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LOW POWER PHOTOVOLTAIC SYSTEMS
FOR NORTHERN APPLICATIONS

RENEWABLE ENERGY BRANCH

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ABSTRACT

A laboratory evaluation of lead-acid batteries at -40°C was conducted. These batteries had been in service in northern sites operated by the Water Survey of Canada. Performance data on discharge-charge cycling shows no deterioration of the batteries characteristics. At the same time a survey was conducted to identify other battery types that could be applied to similar sites. The performance of PV module/battery systems was simulated by extensive computer modelling using PVFORM with solar data and system parameters obtained for selected sites. Extensive model customization and coding was performed to adapt the program to typical Canadian conditions.

The results of the simulation indicated the need for rewriting PVFORM to make it more attractive to Canadian agencies, designers and users.

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EXECUTIVE SUMMARY

One of the most economically feasible applications of photovoltaics is the supply of low level power in extremely remote sites. For example, many monitoring sites in the Canadian far north have no access to the electric power grid and the transportation costs for primary batteries or diesel fuel are prohibitive. In those sites where the power requirements are fairly low, the economics of PV power is particularly good.

Because of the limited commercial potential, little research has been done on northern low power photovoltaic systems. For different sites in the far north, the yearly radiation profiles can be radically different in character as well as quantity. The interactions between these diverse profiles, the solar array, the battery and the load can be very complex. A means of estimating the design parameters in a straight forward manner does not exist. Because the sites of interest are remote and very rarely visited, the design must provide a reasonable reserve capacity. On the other hand, the high cost of transportation to these sites strongly discourages the over-sizing of components.

The present program had three main objectives: i) to conduct a laboratory evaluation of lead-acid batteries that had been in service for two years, ii) to survey other potential battery types, iii) to study the performance of PV module/battery systems by computer modelling, using solar data obtained in selected sites.

The test program of lead-acid batteries (Varta P125) consisted of a discharge-charge protocol at -40°C which simulated the operation of a Water Survey of Canada water monitoring site.

A pocket plate nickel-cadmium (Ni-Cd) battery (Marathon Alcad MP80) was also selected for evaluation.

To prototype and understand PV systems, an existing photovoltaic system simulation package, PVFORM, was customized for northern, low power applications.

The simulation is of one full year with hourly time resolution. The solar simulation module was bypassed in favour of estimates obtained from AES. Extensive model customization and coding was performed to adapt PVFORM to typical Canadian conditions. Simulations were performed for two sites; Fort Smith (lat. 60°) and Resolute (lat. 75°). System parameters were derived from information provided by TES on a Coppermine River site (lat. 67 degrees).

Lead-acid industrial batteries exhibited a performance comparable to that of new batteries after a two year deployment in the north. It would be interesting to compare their performance to that of other types such as the ones identified in this program.

System simulation using PVFORM has shown the potential of well designed, well sized PV systems for low power applications in Canada. However, better simulation tools are required. Northern Canadian conditions are unique in that they combine remoteness with low insolation and low ambient temperatures for long periods. Models and computer programs developed for more benign environments are limited in this case.

Rewriting PVFORM in Pascal to model panel/battery I-V characteristics and provide customization for low power northern sites could provide Canadian government agencies, designers and users with a powerful design tool.

RESUME

1. INTRODUCTION

This report describes the work carried out by the Ontario Research Foundation on contract serial number 23216-6-6115/01-SZ. It deals mainly with the performance evaluation and modelling of low power photovoltaic systems for northern applications.

Solar photovoltaic generation of electric power is attractive for environmental and economic reasons. It is particularly well suited for remote sites where transportation and fuel supply costs are high [1]. The extreme environmental conditions encountered in remote Canadian sites, the Scandinavian countries and the southern tip of South America present unique difficulties due to the combined effects of low temperatures, long periods of darkness and remoteness. Additional system information and design criteria for system integration, together with appropriate standard tests, must be developed to satisfy these markets. All these PV power users require very reliable, long cycle life systems with unattended operation at competitive costs. Photovoltaic systems with energy storage are becoming economically attractive. At the present time, batteries provide the best form of storage because of their availability and relatively low cost. Batteries/PV systems can free a site from any dependence on diesel generators and transportation of fuel. However, the demands on a battery in a PV system are rather unique. They must possess high charging efficiency, low self-discharge, low maintenance, ability to withstand temperature extremes and operate at various states of charge.

The Massachusetts Institute of Technology has conducted extensive operational tests on batteries for PV systems [2]. All the systems were equipped with different types of lead-acid batteries [3]. All the sites had loads in the 5-25 KW range and were situated throughout the U.S. Not one was exposed to the extremes of low temperatures and degraded sunlight conditions normally encountered in northern Canada. A good survey of PV technology and battery storage was conducted by the Alberta Government Telephone Company [4]. Both field trials and laboratory tests, however, did not follow rigorous cycling procedures as to produce reliable data on the temperature behavior of the batteries. Also, the minimum temperature achieved was -15°C which is not representative of many Canadian sites. NRC conducted preliminary studies in the early eighties on low power stand alone PV systems [5]. The conclusions of this limited study indicated that low insolation levels and low temperatures do not preclude the use of PV systems with battery storage in remote sites. ORF conducted tests on industrial batteries being considered by the Water Survey of Canada [6]. These batteries were tested under discharge conditions resembling those of a typical sub-arctic water level data collection site. The objectives of the study were threefold: i) to determine whether the battery capacity was enough to operate for 60 sunless days at 0.1A discharge current and a temperature of -40°C , ii) to determine battery performance under cyclic discharges, and iii) to determine if the batteries would accept a short daily charge. The results of this study were such that the Water Survey of Canada later deployed these batteries in the field.

The Water Survey of Canada operates a network of 2700 water level gauging platforms in northern Canada. Their present requirements are 1Ah/day with a projected 10 Ah/day when water quality equipment

is added to some platforms. A typical power load consists of a servo manometer, an encoder and a data collection unit. Real time transmission of hydrometric and related data to a central office is done via satellite. Many of these installations are powered by a 10, 20 or 30 W_p PV panel and two 6V industrial type batteries, each with a nominal capacity of 212 Ah at the 8 hours discharge rate (T=25°C).

Data is lacking on battery selection and interconnection optimization to design a stand alone system to operate with long cycle and high reliability at low cost. Due to the remoteness of most sites, transportation costs of equipment and personnel are important concerns.

2. OBJECTIVES

The general objectives of the present program are to establish a capability to analyze low power PV systems operating in the Canadian north. This would provide the design parameters required for system integration and optimization. It would also permit the testing of such power systems before deployment. In Phase I of this program, the objectives were: i) to conduct a laboratory evaluation of batteries that have been in service for two winters, ii) to conduct a survey of other potential battery types for the same application, iii) to study the performance of PV module/battery systems by computer modelling, using solar data obtained in selected sites.

3. METHOD

3.1 Lead-Acid Battery Performance Evaluation

Two 6V Varta P125 lead-acid industrial type batteries, having a nominal capacity of 212 Ah at the 8 hour discharge rate ($T=25^{\circ}\text{C}$) were evaluated. A copy of the manufacturer's specification is included as Appendix 1. The current cost of each battery is approximately \$100. These batteries had been in service in a Water Survey of Canada site from the summer of 1984 to the spring of 1986.

The test program consisted of a discharge protocol at -40°C similar to that performed by ORF in the spring of 1985 on similar batteries [6]. The batteries were fully charged according to the manufacturer's directions, at 6.99V (2.33V per cell) and 40A at room temperature until the specific gravity in a cell reached values between 1.270 - 1.285. The batteries were then placed in a cold chamber at -40°C . The batteries were discharged at 0.1A until a voltage of 5.25V (1.75V per cell) was reached. Following this discharge, the temperature was increased to 20°C and the specific gravity re-measured. The batteries were charged again and the temperature lowered to -40°C .

Field operating conditions were simulated by a discharge at 3A for 30 seconds once every 3 hours. During the remaining 2h 59m 30s, one battery was discharged at 0.05A and the other at 0.07A. The cycle continued for 40 days. A 2 hour charge at 0.6A every 24 hours and a low discharge period of 59m 30s were programmed to run for an additional 27 days. The batteries were then warmed up to 25°C and recharged.

3.2 Survey of Batteries

A survey of batteries was conducted to determine new types that could meet the requirements of the present application.

Lead-acid and alkaline (Nickel-Cadmium) batteries are the only types currently mass produced. Lead-acid batteries are the most common for PV systems because of their cost, availability and relatively good performance. They possess high charge efficiency (~90%) and good depth of discharge (~20%). The depth of discharge and the voltage are affected by low cell temperature which in turn, decreases the available capacity. Moreover, as the temperature drops, the electrolyte specific gravity should be maintained to avoid freezing and permanent electrode plate damage. This is especially critical during periods of deep discharge at low temperatures when batteries should be maintained at a high state of charge. Perhaps a major disadvantage of lead-acid batteries is their relatively low storage capacity density because of the lead employed in their construction.

Ni-Cd batteries offer a long operating lifetime (500-2000 cycles) compared to that of lead-acid (300-1000 cycles). The charge efficiency is lower than that of lead-acid batteries but, unlike them, their voltage and electrolyte specific gravity are fairly independent of the state of charge and they are less affected by low temperature operation. They are, however, approximately five times as expensive as lead-acid batteries at the present time. Further refinements in the manufacturing of Ni-Cd batteries could eventually close the price gap with the lead-acid type. This, plus the capability of Ni-Cd to operate at reduced charge for long periods and reduced freezing propensity, should make this type of battery a strong candidate as an energy storage medium for PV systems.

Table 1 shows the battery types identified in this survey, together with their main characteristics.

Table I
Battery Types Identified

<u>Type</u>	<u>Manufacturer</u>	<u>Voltage</u>	<u>Model</u>	<u>Capacity</u> (Ah)	<u>Approx. Cost</u>
Pb-acid	Varta	6	P125	212 (8 hr)	\$100
Pb-acid	Marathon	6	CPMF200	192 (8 hr)	\$300
Ni-Cd	Marathon	6	MP80	82 (10 hr)	\$500
Ni-Cd	Saab-Nife	6	SUN 14-5	139 (5 hr)	\$600

3.3 System Simulation

A system simulation program, PVFORM was developed by Sandia Labs and adopted to model the system under study [7].

PVFORM is a full-system photovoltaic simulation package. It models systems containing various combinations of photovoltaic panels, lead-acid batteries, steady or variable loads, backup power sources and power grid interconnections. The simulation is of one full year with an hourly time resolution. Tests conducted at Sandia have shown the predicted values to be within 1-5% of measured values. Given certain site specific meteorological data, the model can simulate a system where the photovoltaic array is fixed or tracking at any arbitrary orientation.

The portion of the model used here includes photovoltaic panels, storage batteries and a low power hourly variable load. The solar simulation module is bypassed in favour of equivalent estimates made by the Atmospheric Environment Service (AES).

3.3.1 Radiation Models

The solar model in PVFORM accepts data on a "typical meteorological year" (TMY) specific to the particular site. These are hourly records of two pieces of radiation data, ambient temperature and wind speed. The radiation data items are global horizontal and direct normal radiation. Global horizontal radiation is that which would be incident upon a horizontal upward facing surface. The direct normal radiation is the direct component of the sun's radiation (i.e. omitting diffuse and reflected components) that would be incident upon a flat surface that is tracking the sun (whether obscured by clouds or not).

TMY data is not directly available for northern Canadian sites. Actual hourly data for specific years is, however, available from AES. Thus, all simulations in this report are based on data from the year 1985. The only radiation data readily available for northern sites was global horizontal. Direct normal radiation data could presumably be approximated from the global horizontal and other recorded parameters such as ambient temperature using radiation models studied at AES. However, this would use the output of one imperfect model (AES) to provide the input to another imperfect model (PVFORM), the second of which is potentially very inaccurate for high latitudes. This problem was eventually circumvented by bypassing the PVFORM solar model completely. Along with the recorded meteorological data for each site, the Atmospheric Environment Service was requested to provide radiation estimates for a vertical south facing surface. These estimates were based on radiation models developed largely in Canada.

3.3.2 Model Customization and Coding

As it stands, PVFORM has a number of shortcomings when used to simulate low power systems in the far north. Many of these weaknesses were overcome, at least partially, within the time frame of this contract. Others can only be dealt with effectively by developing array and battery models better suited to low-power arctic simulations and implementing them in a completely rewritten version of the software. The temperature insensitivity of the battery model is a serious limitation specially for systems that operate at very low temperatures.

Very serious consideration was given to the possibility of rewriting PVFORM in Pascal to model panel and battery I-V characteristics and provide some other customization for low-power northern sites. When it became apparent that no I-V characterization existed within either the panel or the battery models, this option was deferred as too costly. It is hoped that in a future phase of work, a new version could be written.

PVFORM was developed in the United States and so assumes a less severe winter climate without the long dark periods of the arctic. The primary battery charge and discharge cycle is probably assumed to be of the order of hours or days rather than over the year. The simulation always begins on January 1st. This is a difficult time of year to choose an initial state of charge for the battery in a system in the far north. This limitation was eliminated. The accuracy of the solar model has not been confirmed for high latitude winters. This issue was finally circumvented by bypassing the PVFORM solar model completely and using radiation estimates for a vertical south facing surface provided by the Atmospheric Environment Service. The data from AES is specific to a given year, in this case 1985. It is not a long term average, nor is it necessarily a worst case year.

PVFORM is geared for use on systems in relatively populated regions. The assumption of a backup power source or connection to the power grid encourages the use of a model optimized for a short term battery cycle. As well, the battery is assumed to be located indoors. The battery model has no ambient temperature dependence. This limitation can only be overcome by developing a new battery model based partly on the existing PVFORM model and largely on the experimental data being collected during this contract on low temperature, long term battery performance.

PVFORM was intended to model systems of much higher power than those typically encountered in the far north. With higher power systems, the use of peak-power tracking electronics is feasible. PVFORM takes advantage of this and does not attempt to model the separate current and voltage components of the array and battery powers. However, the developers of PVFORM at Sandia National Labs, have observed comparable long term performances between direct coupled systems like those used in the far north and peak-power tracking systems with their associated losses. A complete solution to this source of error would require a complete rewrite of PVFORM. This option was seriously considered, but it was recognized that it could not be achieved during this contract.

PVFORM has a number of characteristics which make it awkward to use. Many of these flaws are probably throwbacks to its mainframe heritage. There is no operator feedback while it is running so it is impossible to know if it is running properly, or at all. When the operator specifies parameters that are out of the expected range, default values are substituted without notifying the operator. This is an extremely dangerous situation. The various input and output data files have fixed file names, so multiple simulations require extensive and diligent file renaming. Detailed

output of the battery state of charge is the most important information for judging the reliability of a system. This can only be output as part of an optional 1.2 megabyte data file. A number of arbitrary and inconvenient assumptions are made about what disk drives are used for what input and output data files. After completing a one year simulation, which takes about 25 minutes on a 4.77 MHz PC with a math co-processor chip, the many screen pages of results are dumped to the screen, most of them disappearing from view unless caught by an alert operator. There is no easy means to have PVFORM run multiple simulations unattended. Many of the parameters are stored in data files with too few digits of precision for low power applications. All of these problems relating to the ease and reliability of program operation were rectified.

Two serious bugs were discovered in the battery model. One of them was a subtle but very significant error in the discharging cycle. The other was particularly critical for arctic applications having its effect while the battery was below 20% of full charge. Both of these bugs were corrected after extensive consultation with the programmer at Sandia Labs. It is understood that Sandia Labs will incorporate these corrections into the official version of PVFORM.

4. RESULTS AND DISCUSSION

4.1 Lead-Acid Batteries Testing at Low Temperatures

4.1.1 Constant Current Discharge

Two Varta 6V P125 lead-acid batteries which were in service for two years in a data collection station were tested to determine if they had deteriorated in service. The manufacturer's specifications are included in Appendix 1.

The two batteries (arbitrarily designated No. 1A and No. 2A) were fully charged, according to the manufacturer's directions, to 6.99V maximum (2.33V per cell) and 40.0A maximum current at room temperature until the specific gravity of each cell was in the range 1.270 to 1.285. Table II lists the charge current and average specific gravity for each battery during the initial charge.

The batteries were placed in a cold cabinet which was set to cool to, and then maintain, a temperature of -40°C . Discharge of the two batteries to 0.10A commenced after the cabinet had equilibrated at -40°C . The discharge equipment was set to terminate the discharge at 5.25V (1.75V per cell) which is just below the "knee" of the discharge curve.

Figure 1 represents the discharge curves (at -40°C and 0.1A) of the two batteries. The cutoff voltages were reached after 166.0 A.h (69.2 days) and 176.3 A.h (73.5 days) for batteries 1A and 2A respectively. The nominal capacity of these batteries was 212 Ah at the 8 hour discharge rate at 25°C (from the manufacturer's specifications).

Following the discharge, the batteries were warmed up to 20°C in the cabinet and removed. The specific gravities of the three cells of battery 1A were: 1.115, 1.110, and 1.110 respectively. The specific gravities of battery 2A were: 1.110, 1.120, and 1.120 respectively. The average specific gravity of the electrolyte in the six cells was 1.114. The manufacturer cautions against operation below 1.140 at 25°C . The batteries were discharged past the "knee" in the discharge curve. Thus, a lower specific gravity was not surprising.

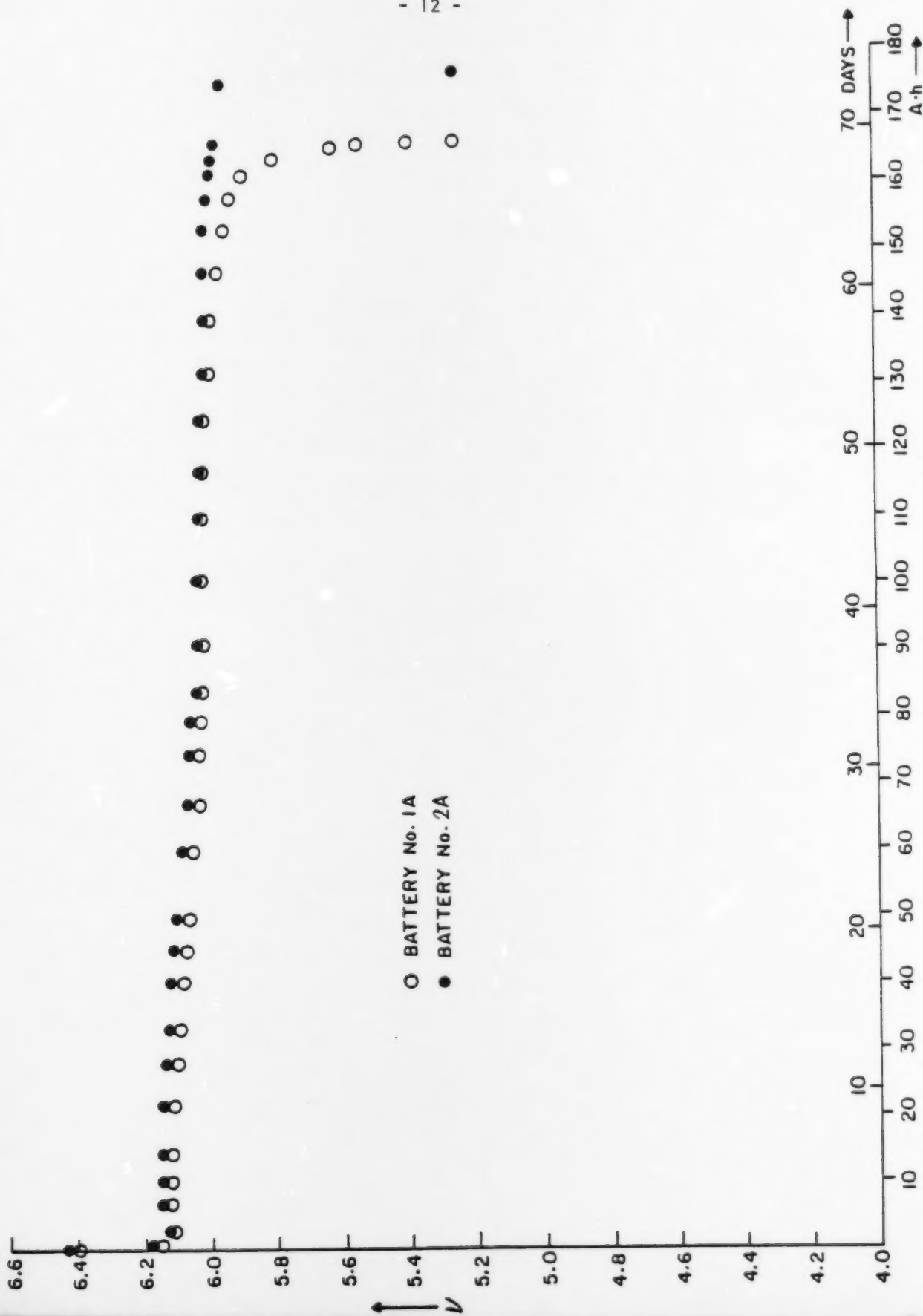


FIGURE 1: FIRST DISCHARGE (0.1 A, -40 °C)

TABLE II

Charge Acceptance - Initial Charge
(40A Max., 6.99V Max.)

Time	<u>Battery 1A</u>		<u>Battery 2A</u>	
	Current	Avg. Specific Gravity	Current	Avg. Specific Gravity
	(A)		(A)	
1.0	10.53	1.235	9.63	1.240
8.1	2.51	1.240	2.81	1.245
23.0	1.43	1.253	1.47	1.262
31.6	1.11	1.258	1.18	1.263
37.6	0.99	1.268	1.05	1.275
40.8	1.04	1.272	1.08	1.277

The batteries were recharged at a maximum of 2.33V per cell (6.99V) and 40 A maximum current. The recommended specific gravity range (1.270 to 1.285) was reached for battery 1A in 166 hours and in 142 hours for battery 2A. Table III lists the current and average specific gravity for each battery during the recharge.

4.1.2 Cyclic Discharge

The batteries were returned to the cold cabinet and cooled to -40°C . The test equipment was programmed to provide a 3.0 A discharge for 30 seconds once every 3 hours. During the remaining 2 hours, 59 minutes and 30 seconds, battery 1A discharged at 0.05 A and battery 2A discharged at 0.07 A (the lower limits of the two discharge modules).

This procedure continued for 40 days during which time the voltage of battery 1A declined to 6.19V prior to the final 3.0 A discharge of the last day and to 6.05V at the end of the 3.0 A discharge. The corresponding voltages for battery 2A were 6.16V and 6.03V, respectively. Battery 1A had been discharged 55.9 A.h and battery 2A had been discharged 75.0 A.h.

Figures 2 and 3 represent the discharge/charge curves for batteries 1A and 2A for the duration of the test.

4.1.3 Cyclic Discharge with Daily Charge

The test equipment was reprogrammed to provide a 2 hour charge at 0.60 A every 24 hours and one of the low discharge periods was shortened to 59 minutes and 30 seconds. This procedure continued for 27 days during which time the voltage of battery 1A increased

slightly (despite a net 0.10 A.h/day discharge) to 6.22V prior to the last 3.0 A discharge of the last 24 hour cycle and decreased to 6.09V at the end of that 3.0 A discharge. The corresponding voltages for battery 2A at the above times were 6.19V and 6.04V, respectively (0.54 A.h/day net discharge). Battery 1A had been discharged a total of 58.6 A.h and battery 2A had been discharged a total of 88.6 A.h. The observed increase in terminal voltage despite a net discharge, may be the result of the breaking up of boundary layers in the electrolyte due to charging.

○ VOLTAGE AT THE END OF THE LAST 0.05 A DISCHARGE IN A 24 HOUR CYCLE
 □ VOLTAGE AT THE END OF THE LAST 3.0 A DISCHARGE IN A 24 HOUR CYCLE
 (FOLLOWED BY A 0.60 A DAILY CHARGE)

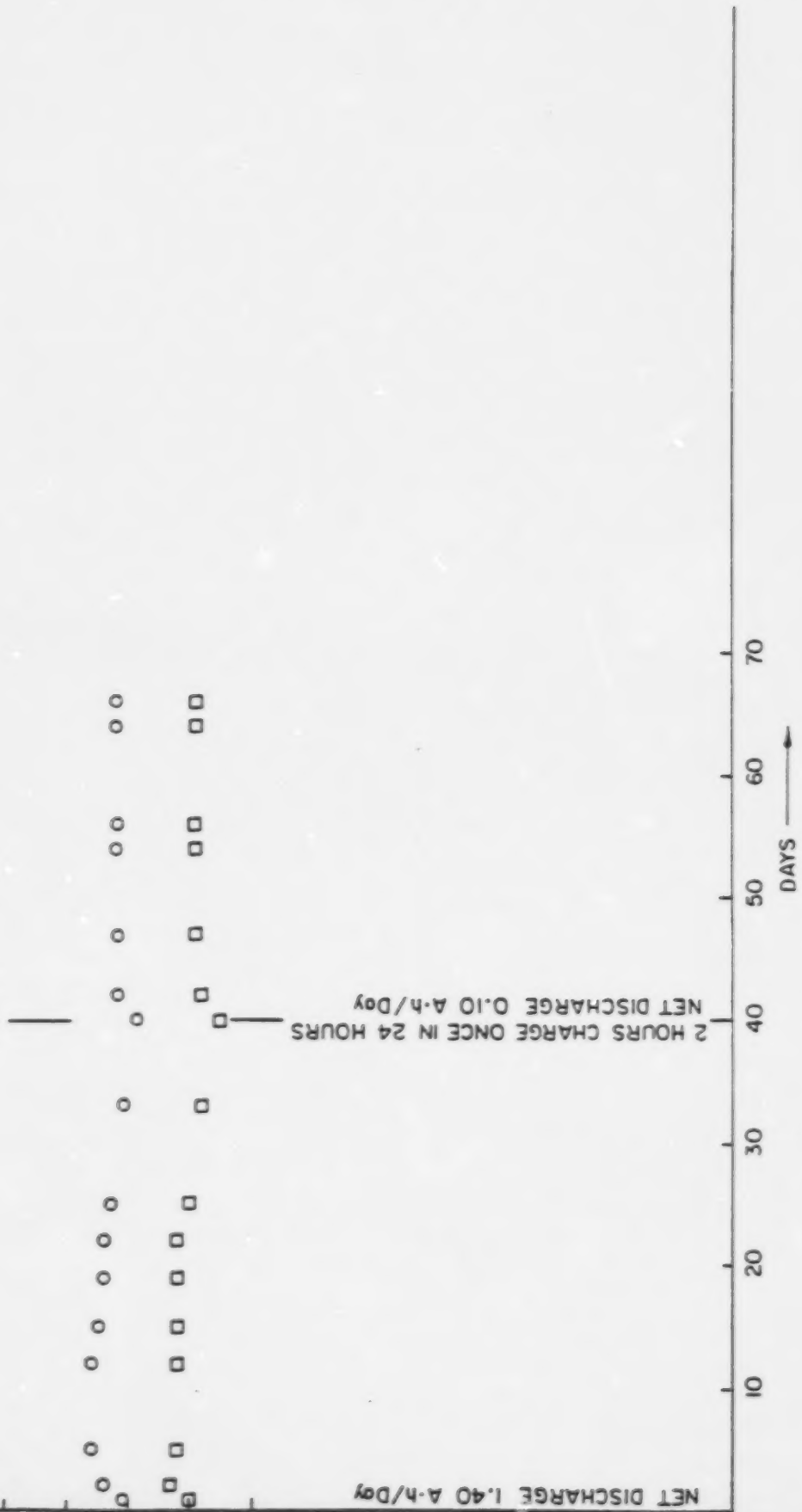


FIGURE 2: SECOND DISCHARGE - BATTERY No. 1A (-40 °C)

○ VOLTAGE AT THE END OF THE LAST 0.07A DISCHARGE IN A 24 HOUR CYCLE
 □ VOLTAGE AT THE END OF THE LAST 3.0A DISCHARGE IN A 24 HOUR CYCLE
 (FOLLOWED BY A 0.60A DAILY CHARGE)

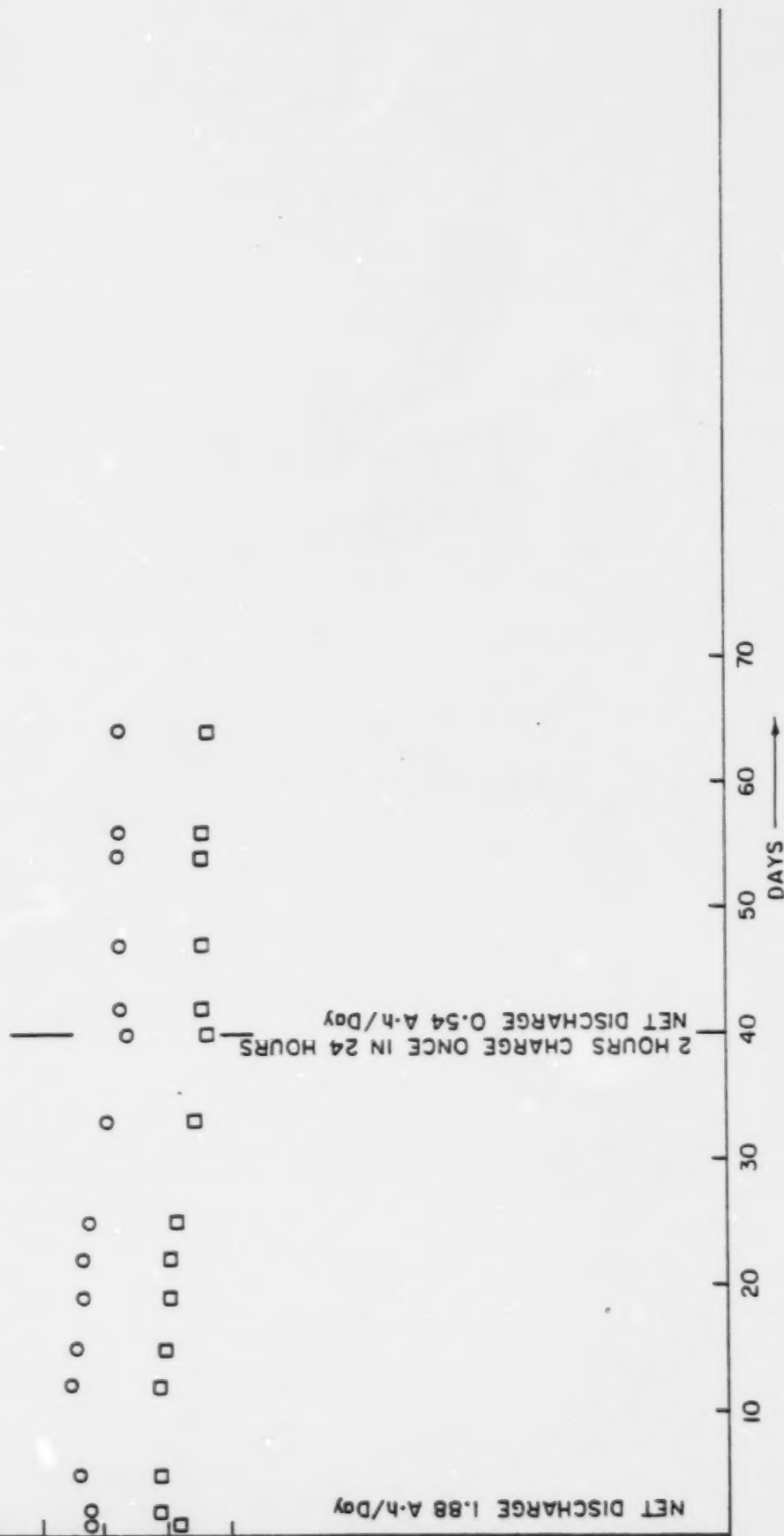


FIGURE 3: SECOND DISCHARGE - BATTERY No. 2A (-40°C)

TABLE IIICharge Acceptance - First Recharge
(40A Max., 6.99V Max.)

Time	<u>Battery 1A</u>		<u>Battery 2A</u>	
	Current	Avg. Specific Gravity	Current	Avg. Specific Gravity
	(A)		(A)	
4.2	8.83	1.145	7.93	1.160
21.9	0.94	1.208	1.03	1.225
49.5	0.68	1.247	0.73	1.252
76.5	0.66	1.255	0.71	1.268
125.9	0.56	1.272	0.60	1.283
165.0	0.55	1.280		

The batteries were warmed up to 25°C in the cabinet and removed. The batteries were recharged at a maximum of 2.33V per cell (6.99V) and 40.0 A maximum current. Battery 1A reached the required specific gravity range in 27 hours and battery 2A in 52 hours. Table IV lists the current and average specific gravity for each battery during the recharge.

The initial charging of these batteries required a longer period than that of the new batteries tested two years ago. This can be explained by the fact that they were removed from service at the end of the winter season when their state of charge was low.

There was very little difference in the 0.1 A discharge curves between these batteries and the new batteries tested two years ago. The two new batteries had reached 1.75V per cell in 68.3 days and 68.1 days (163.9 and 163.4 A.h), respectively [6]. The two year old batteries reached 1.75V per cell in 69.2 days and 73.5 days (166.0 and 176.3 A.h), respectively. Therefore, the batteries had experienced a slight gain in capacity after two years of operation. Typically, lead-acid batteries experience an apparent gain in capacity during their first few operating cycles.

Recharge of the two year old batteries took 166 and 142 hours, respectively compared with 136 and 156 hours respectively, in the earlier test program. Again, this indicates little change in performance.

The performance of the two pairs of batteries during the cyclic testing was similar with the two year old batteries showing slightly better performance. The voltages prior to, and at the end of, the last 3.00 A discharge of the period are compared for the first two cycles from the previous study and the two cycles of this study in Table V.

TABLE IV

Charge Acceptance - First Recharge
(40A Max., 6.99V Max.)

Time	<u>Battery 1A</u>		<u>Battery 2A</u>	
	Current (A)	Avg. Specific Gravity	Current (A)	Avg. Specific Gravity
21.0	1.67	1.268	1.73	1.280
27.5	1.29	1.275	1.35	1.285
35.6	1.09	1.280		
53.3	0.82	1.283		

TABLE V

Comparison of Voltages at The End of
The First Two Periods of The Cyclic Test

Voltages Prior to and at the End of The
Last 3.0A Discharge of the Cycle

<u>Cycle (a)</u>	<u>Battery 1</u>	<u>Battery 2</u>	<u>Battery 1A</u>	<u>Battery 2A</u>
1	6.18-6.05	6.14-6.01	6.19-6.05	6.16-6.03
2	6.20-6.07	6.13-6.01	6.22-6.09	6.19-6.04

Notes

(a) Cycle 1: 3.0A discharge for 30 seconds once every 3 hours with batteries 1 and 1A discharging at 0.05A and batteries 2 and 2A discharging at 0.07A the rest of the time. Duration 38 days for batteries 1 and 2 and 40 days for batteries 1A and 2A.

Cycle 2: included a 0.60A charge for 2 hours once in every 24 hours period with one of the low current cycles reduced by 2 hours. Duration 27 days for both pairs.

4.2 New Battery Testing

A pair of pocket plate Ni-Cd batteries (Marathon Alcad MP80) were procured for laboratory testing. The manufacturer's specifications are included in Appendix 1. The current cost of a 6V (five cell) battery is approximately \$500.

The two batteries are currently being tested at -40°C using a similar protocol to that used for the lead-acid batteries. Complete results will be reported after the conclusion of the tests in phase II of the present program.

4.3 System Simulation Results

Simulations were performed for two sites: Fort Smith (latitude 60 degrees) and Resolute (latitude 75 degrees). Meteorological data for the 1985 calendar year was used. Thus, these are not average nor are they necessarily worst case simulations. The data was essentially complete for these two sites. The key radiation data corresponds to a south facing vertical collection surface. The system parameters were derived from information provided to us by T.E.S. obtained in the Coppermine River site (latitude 67 degrees). The nominal values for the primary variables were as follows:

array area:	0.1m^2
battery capacity:	2.0 KWH
hourly load cycle:	0.6, 0.6, 0.9, (repeat), ...W (averaged over each hour)

Nominal values were used for other parameters such as the efficiency and temperature coefficients of the array and the battery charging and discharging efficiencies. A number of other model parameters had to be chosen characterizing such things as the power

conditioning module. The choice for these parameters was somewhat arbitrary since there was no direct analogue for these components in the systems being simulated.

The key criterion used for judging the likely success or failure of a system was the battery state of charge (SOC) through a yearly cycle.

Figure 4 shows the results of a one year simulation for Fort Smith assuming the nominal values for the site parameters. The plot shows the state of charge of the battery over the course of the year. Considering the inappropriateness of portions of the PVFORM model to these sites, the results were surprisingly realistic. When customizing PVFORM for running these simulations, we had judged that, at best some of the model parameters would have to be adjusted by a factor of two or more and the simulations be limited to testing relative sensitivities to model parameters.

The SOC peaks around April and falls off slightly as the summer progresses. This would be due to two factors. Firstly, the solar array is modelled as a vertical south facing surface. During the summer months, much of the day's radiation will be nearly perpendicular to or behind the array surface. Secondly, the vertical surface will be strongly illuminated by snow which may begin to melt in the spring. Figure 5 shows two solar radiation measures for the year at Fort Smith. One of course is for a vertical south facing surface while the other is for a horizontal upward facing surface ("horizontal global"). The advantage of facing the solar panels vertically to the south is clear from these plots. The drop off in the spring and summer radiation for the array surface can be clearly observed.

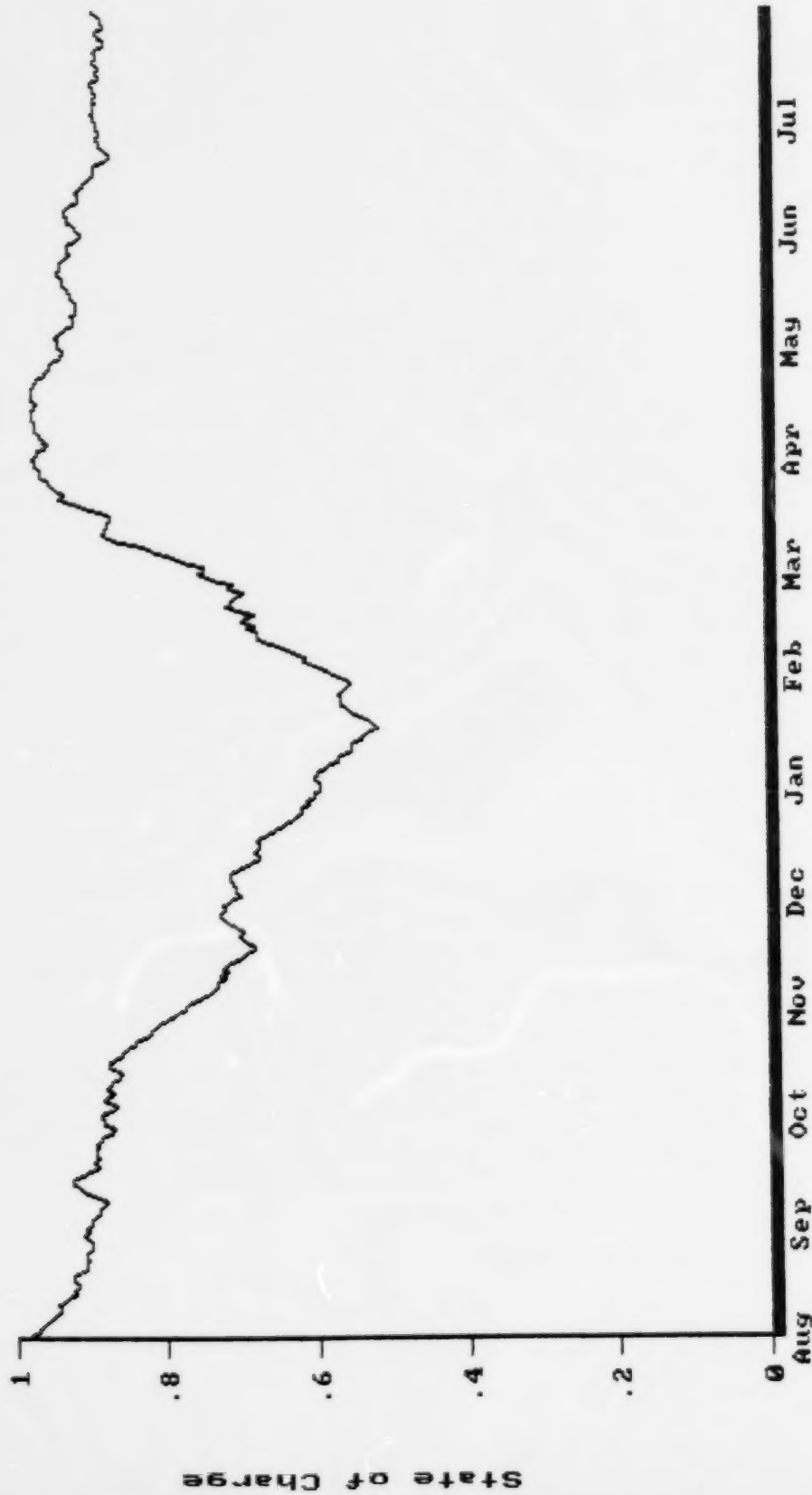


Figure 4 - Yearly State of Charge Profile
Fort Smith
Array Area = 0.1 m²
Battery Capacity = 2.0 KWH

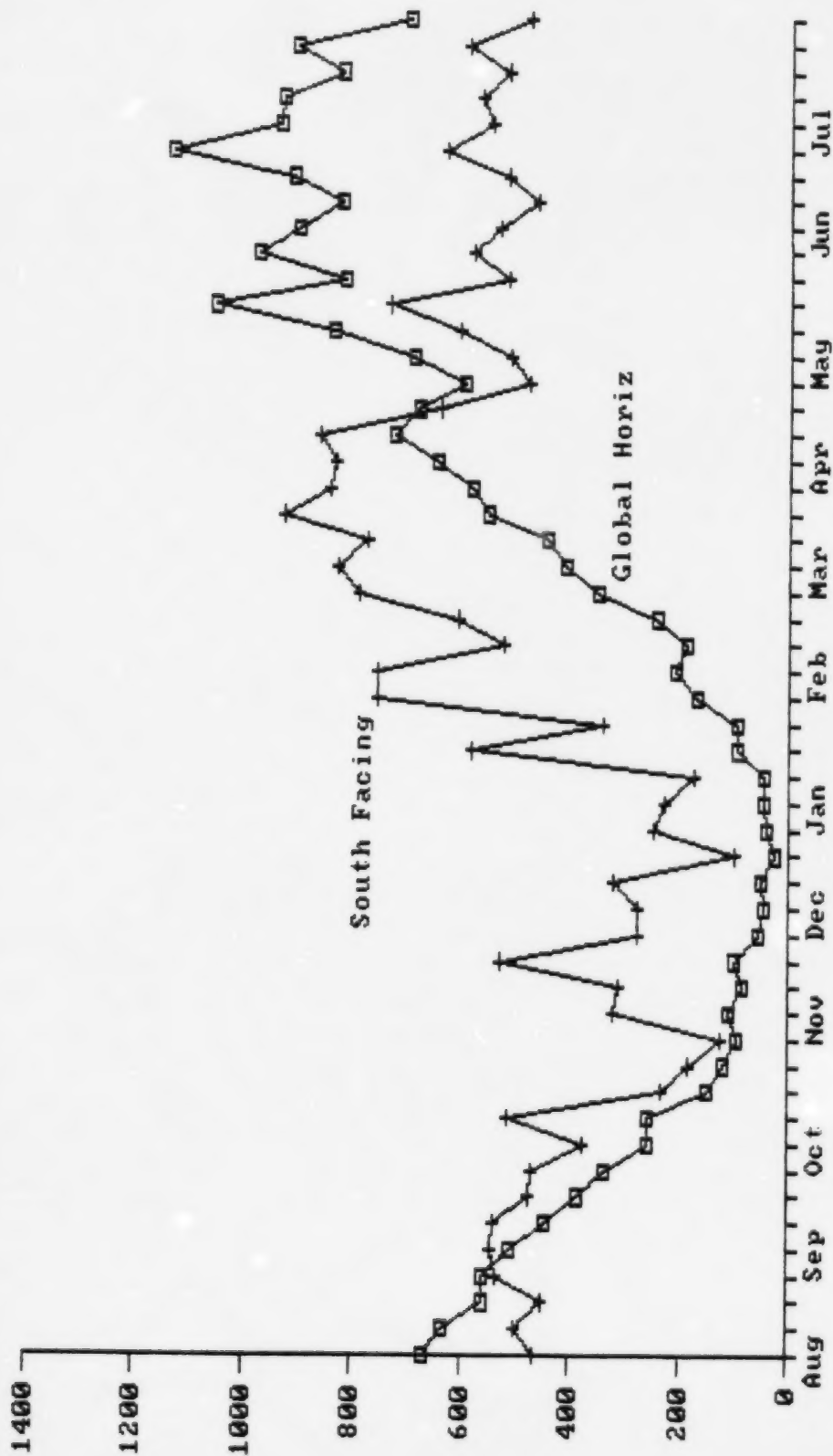


Figure 5 - Incident Radiation
Fort Smith
Yearly Average South Facing = 511 $\text{kJ/m}^2 \text{h}$

One of the parameters required for a one year simulation is the initial SOC of the battery. After the simulation, the final SOC for the same date and time one year later may be significantly different from the initial value. If the simulation were to continue into a second year assuming an exact repeat of the environmental conditions, the system performance would be at least slightly different because of the different initial SOC for that year. By the end of the second year of simulation the SOC may or may not have significantly changed again. Once SOC begins to repeat itself, the model has reached equilibrium in the simulation for that particular year (1985). Subsequent yearly simulations using this equilibrium initial SOC would yield identical system performance. Performances based on the equilibrium initial SOC are the most meaningful for characterizing long term system behavior.

A simulation year in PVFORM normally begins and ends on the midnight of December 31st. At this point, the battery will be approaching its lowest SOC for the year, which usually occurs around January or February. The depth of discharge of the battery during the winter months is the most important indicator of the suitability of the system design for the site. It will be very strongly affected by all of the site and design parameters. Thus it is very difficult to choose a first guess for a SOC occurring during the winter months. Many consecutive years of simulation would likely be required for the SOC profile to reach equilibrium.

PVFORM was modified to accept any month as the start and end of the simulation year. This allows the operator to provide an estimate for the initial SOC for the summer months when the state of charge was expected to be very close to maximum. The one year simulation then begins at that point in the year and proceeds until the same time one year later. Few, if any, additional one year simulations will be needed to determine the exact equilibrium SOC for that time of year.

A simulation was performed for Fort Smith using 0.99 as the initial SOC at the beginning of August. One year later, SOC was 0.885. A second simulation was performed using this new initial SOC and identical environmental conditions. At the end of the second year, the state of charge was again 0.885 which clearly demonstrates it is the equilibrium value for that point in the year.

In figure 6, the SOC is plotted for several values of the initial August 1st SOC. Simulations with a low initial value showed a higher SOC the same time the following year and conversely, those with a very high initial SOC showed slight reductions in value one year later. In this case, all simulations converged to essentially the same value within the year. This illustrates how the systems tend toward an equilibrium SOC profile (provided that they survive the winter). This equalization occurs primarily during the peak charging periods in the spring months.

The array area is an important parameter affecting system performance. Too large an area might cause problems of battery overcharging (not modelled in PVFORM). More seriously, too small an area would result in the battery being discharged too quickly in the fall and not being supplemented early enough in the spring. With a small area, even if the system survived a given winter, the battery may fail to fully charge before the following winter.

To find the sensitivity of the system performance to the array area, a series of simulations were performed, varying only the array area. Results of this sequence are shown in figure 7. While 0.1 square metres appeared sufficient for the system to survive the winter, reducing the area to 70% of that resulted in a system that failed completely by mid-January. Use of 85% of the nominal array area resulted in a system that although it survived the winter, had a state of charge much lower one year later (50% instead of 100%). This suggests that a system yielding a performance similar to that of the 0.1 square metre case (SOC dropping as low as 50%) is in danger of failing on a slightly poorer year.

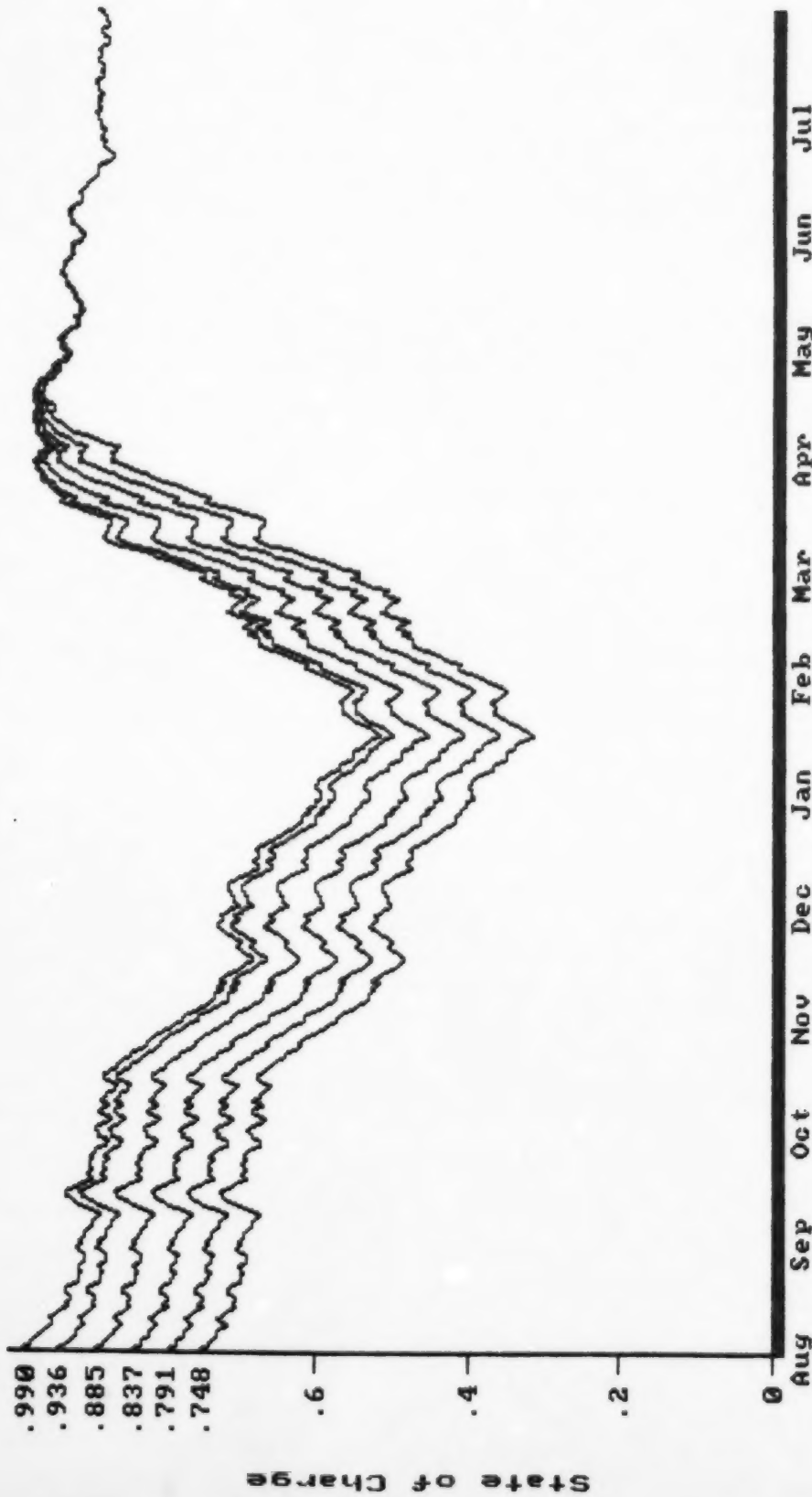


Figure 6 - State of Charge vs. Initial State of Charge
Fort Smith
Array Area = 0.1 m²
Battery Capacity = 2.0 KWH

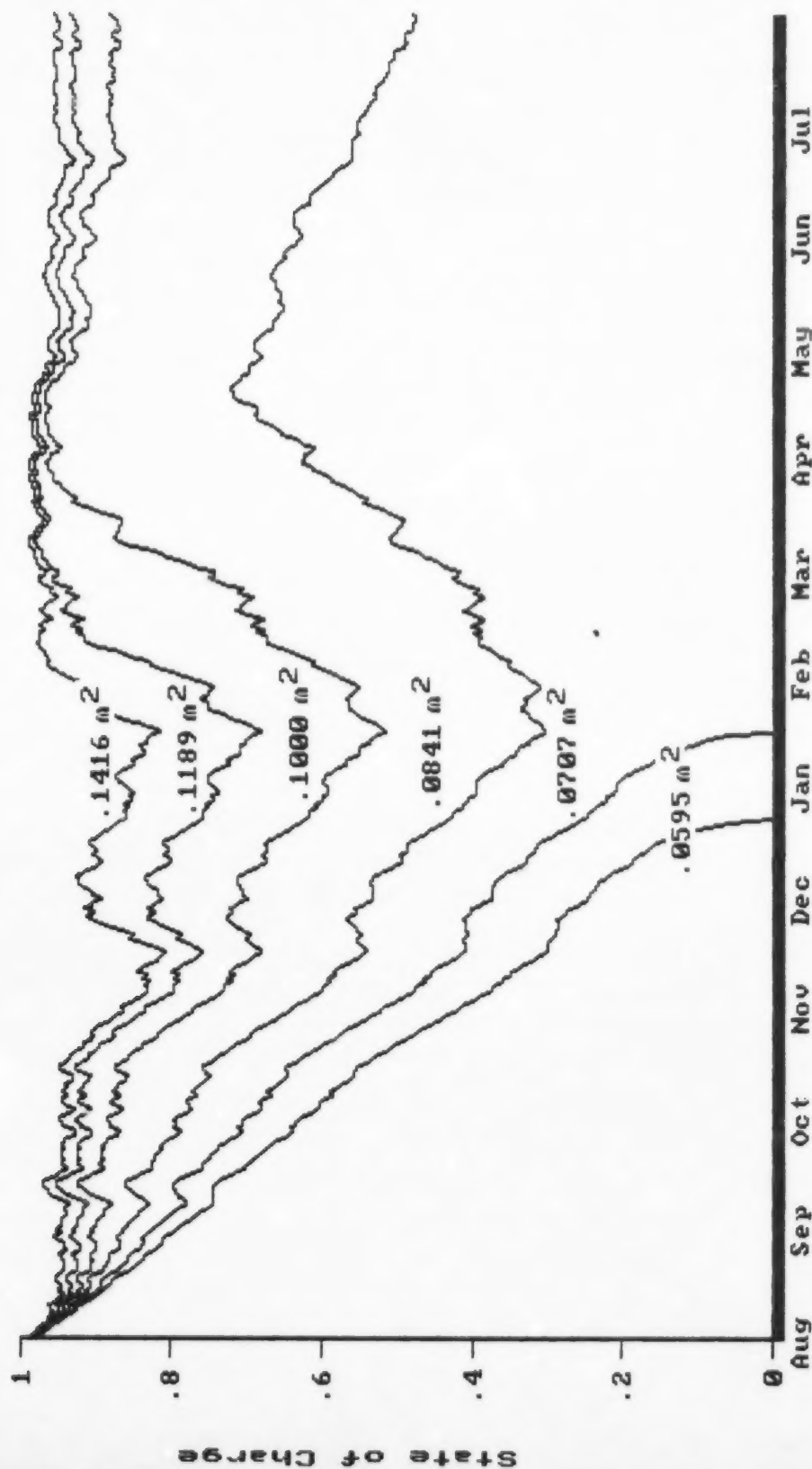


Figure 7 - State of Charge vs. Array Area (m²)
Fort Smith
Battery Capacity = 2.0 KWH

To find the sensitivity of the system performance to the battery capacity, a series of simulations were performed, varying only the battery capacity and leaving the array area at 0.1 square metres. This family of curves is shown in figure 8. The plots suggest that a system performing in a manner similar to the nominal case probably has sufficient battery capacity in reserve.

The same nominal system parameters were tried for a simulation at Resolute. The system failed completely by mid-December. Anticipating reduced available radiation as the problem, simulations with slightly higher and then much higher array area were attempted. These also failed. These three simulations are shown in figure 9.

The radiation profile for Resolute is shown in figure 10. The total yearly radiation on a south facing vertical surface is not much lower for Resolute than for Fort Smith. In 1985, Resolute was exposed to a long term average of $428 \text{ kJ/m}^2\text{h}$ compared to Fort Smith's figure of $511 \text{ kJ/m}^2\text{h}$. The ten year (1967-1976) data base averages are 439 and $495 \text{ kJ/m}^2\text{h}$ respectively. Thus the total quantity of radiation is not the problem. However, complete darkness can be observed for November, December and January. In figure 6, we can observe the steady discharge of the battery beginning in November.

A series of simulations were performed, with an array area only 40% higher than that for the Fort Smith simulations, but with a range of battery capacities. The results of these simulations as shown in figure 11 demonstrate that because of the long dark winter, a battery capacity more than two times that of Fort Smith is required for a system in Resolute. For this system, sufficient array energy appears to be available to charge the heavier battery.

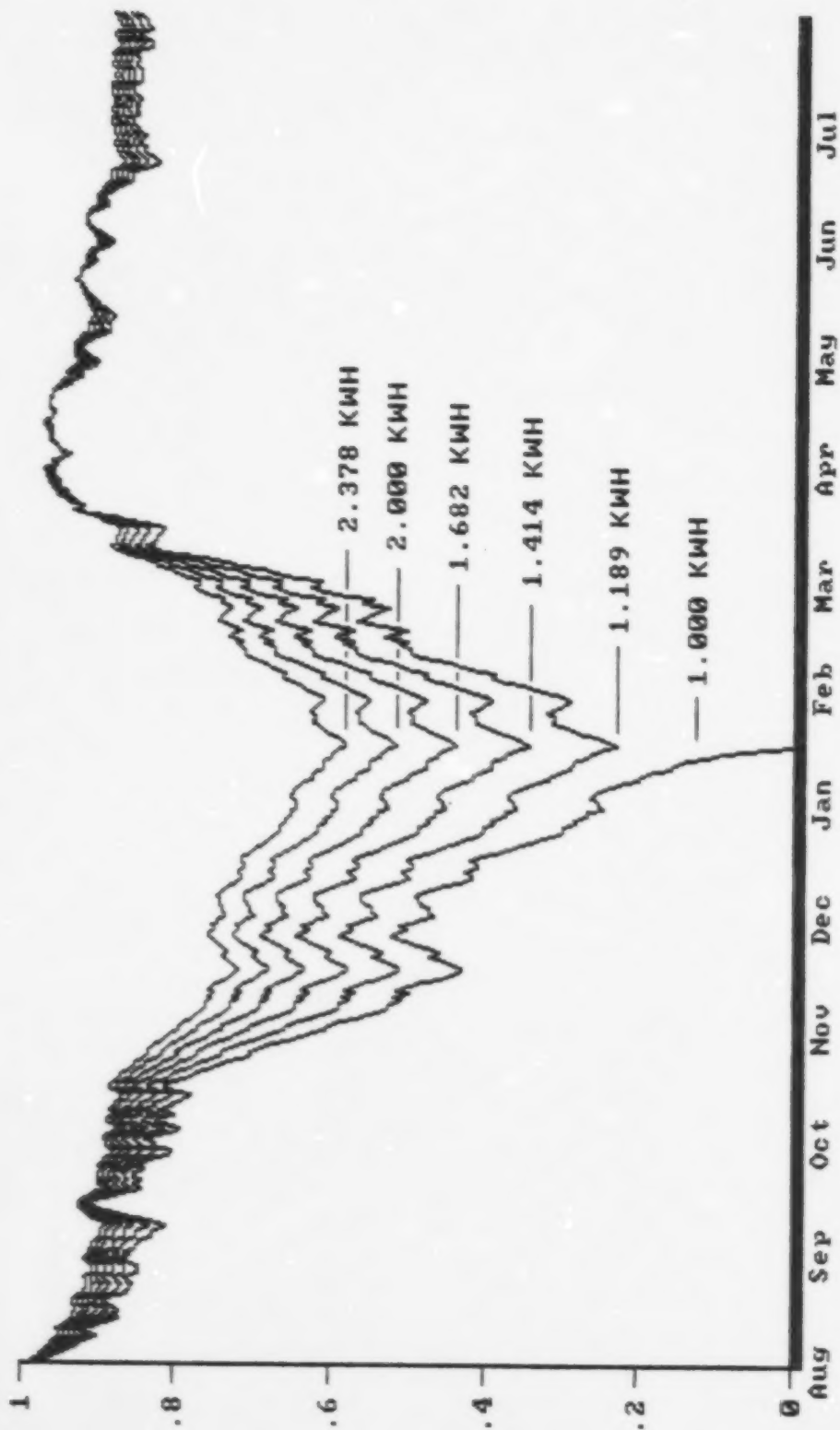


Figure 8 - State of Charge vs. Battery Capacity (KWH)
Fort Smith
Array Area = 0.1 m²

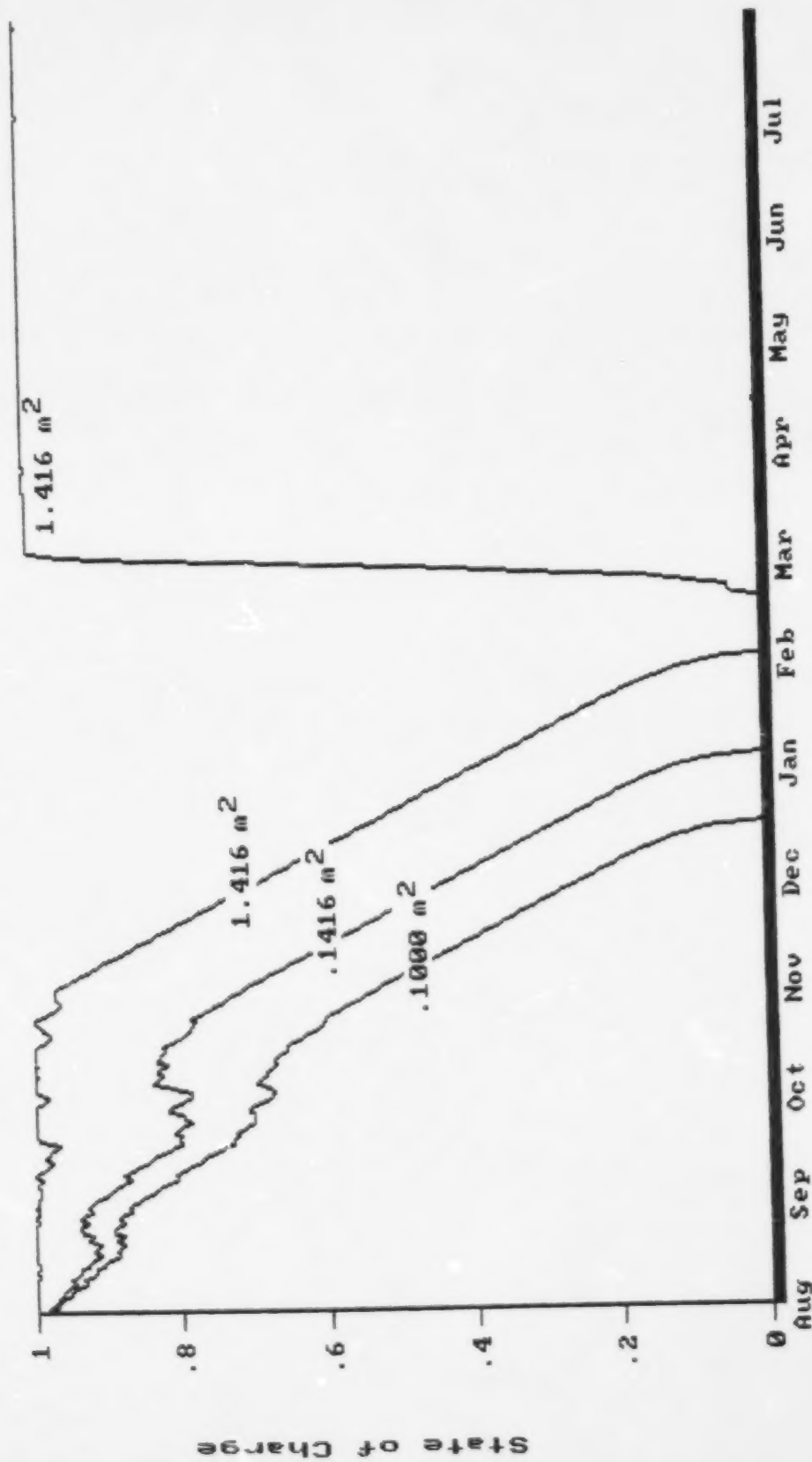


Figure 9 - State of Charge vs. Array Area (m²)
Resolute
Battery Capacity = 2.0 KWH

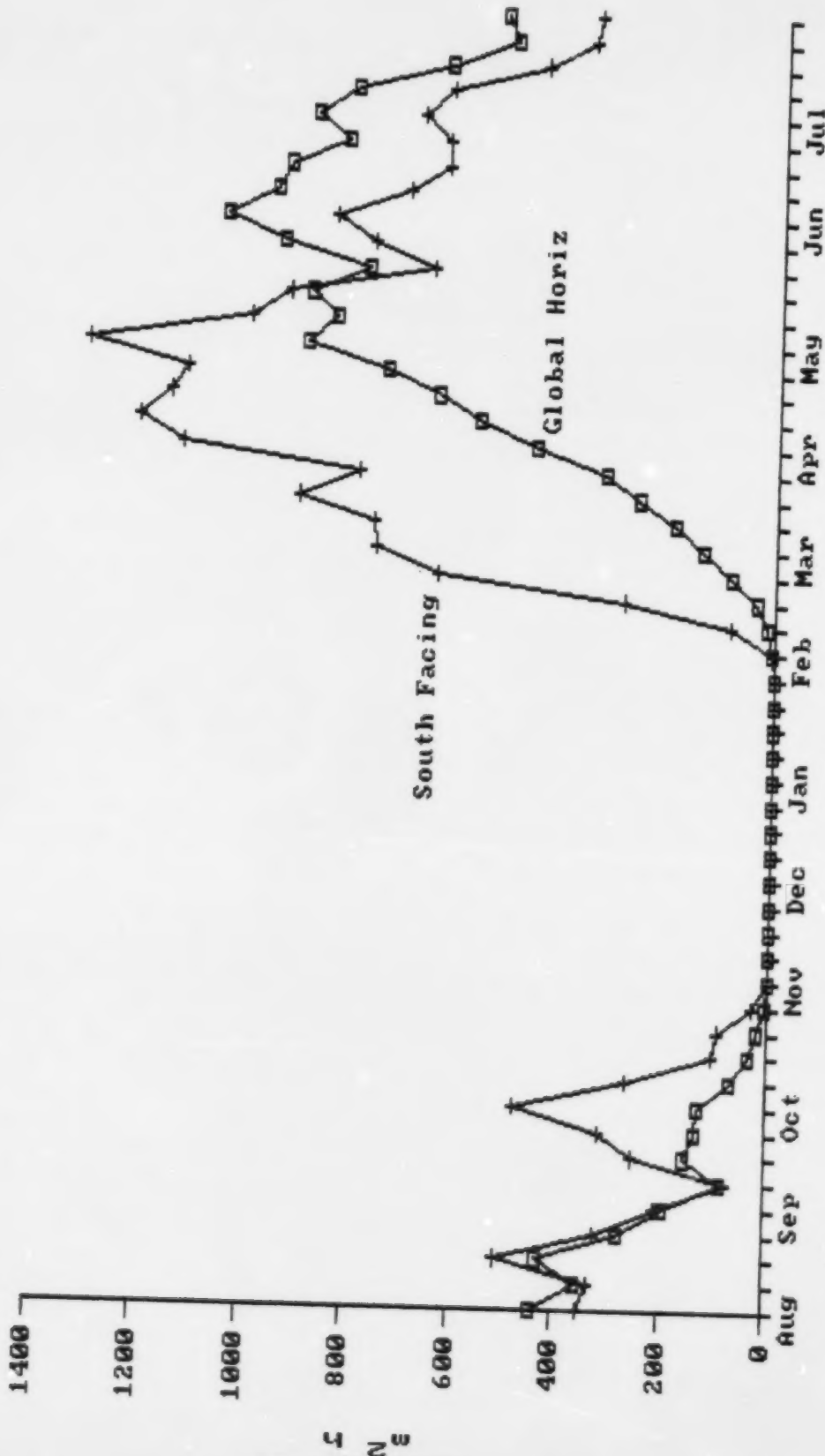


Figure 10 - Incident Radiation Resolute
Yearly Average South Facing = $428 \text{ kJ/m}^2\text{h}$

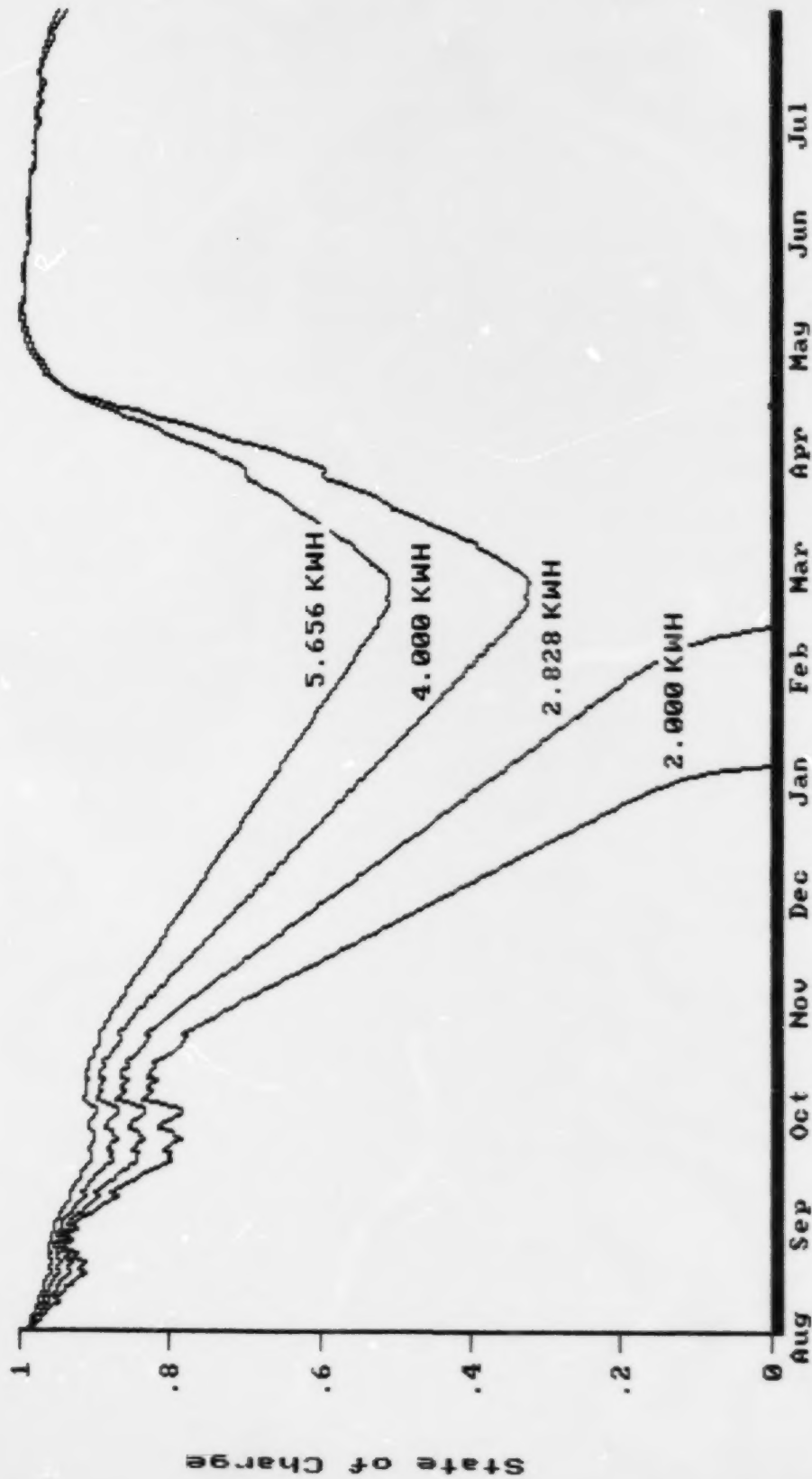


Figure 11 - State of Charge vs. Battery Capacity (KWH)
Resolute
Array Area = 0.1416 m²

5. CONCLUSIONS AND RECOMMENDATIONS

This study has shown that industrial lead-acid batteries can be employed for energy storage, in PV systems designed for low insolation/low temperature operation. Batteries deployed in the field for two years, exhibited discharge-charge characteristics comparable to those of new batteries. Other types of batteries should undergo similar testing, under various temperature regimes, to determine their potential for similar applications. Low temperature performance data is also required for two other reasons. Battery manufacturers do not usually supply that information because they serve a different market. Designers and users are thus limited to guesswork and overdesigning of the power pack. Data on long and short term performance should produce better system design with lower associated costs. Secondly, improved battery simulation models require this data to reflect the inherent temperature sensitivity of the battery, specially at low temperatures.

It is recommended that new battery models for both lead-acid and Ni-Cd batteries be developed to include an ambient temperature dependence. The models should be based partly on the existing PVFORM model and on the experimental data being collected on long term low temperature performance. Such models should overcome the present limitation when simulating unheated systems in the north. Moreover, they would provide a better indication of the accuracy of the current simulation results due to the present assumption that the batteries operate at room temperature.

Simulations carried out assuming a SOC of 0.99 on August 1st were not ideal. It would appear better to estimate the battery SOC during March or April because of the high rate of convergence of the SOC, appearing in Figure 6, during this period. Selecting a value of 1.0 on May 1 may be appropriate, as all lines converge to this value (from Figure 6, it would appear that any SOC from 0.67 to 1.00 at April 1 would have resulted in a "correct" SOC of 0.97 on April 30). Following the spring correction of the SOC, the January low SOC should be accurately estimated, which is probably the most critical point during the year.

Consideration should be given to the range of meteorological years that can be encountered. Modelling of a worst-case year could be of particular value.

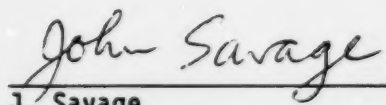
Finally, various difficulties were encountered with PVFORM, both in its operating characteristics and its applicability to northern sites. A new version of this program would make it more useful to designers and users. As a minimum, the rewritten version should include the following: i) a temperature dependent battery model; ii) I-V characterization of the battery and PV panel; and iii) a better user interface.

A customized program could become a very powerful design tool for power systems operating in typical Canadian conditions.

6. REFERENCES

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3. Field Tests of PV Power Systems. L.L. Bucciarelli, ISES Silver Jubilee, Atlanta, May-June 1979.
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5. Design of a Stand Alone Photovoltaic Power System, J.B. Ayer, 16th IEEE Photovoltaic Specialists Conference, 1443-1453, 1982.
6. Testing of Two Batteries (Varta p-125) at -40°C, R.W. Elliott, ORF Report CS 133-84, April 1985.
7. PVFORM - A new approach to photovoltaic system performance modelling, D.F. Menicucci, 18th IEEE Photovoltaic Specialists Conference, 1614-1619, 1985.


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APPENDIX 1

Commercial Literature on Batteries
Selected for Testing

The **VARTA P-125** Industrial battery

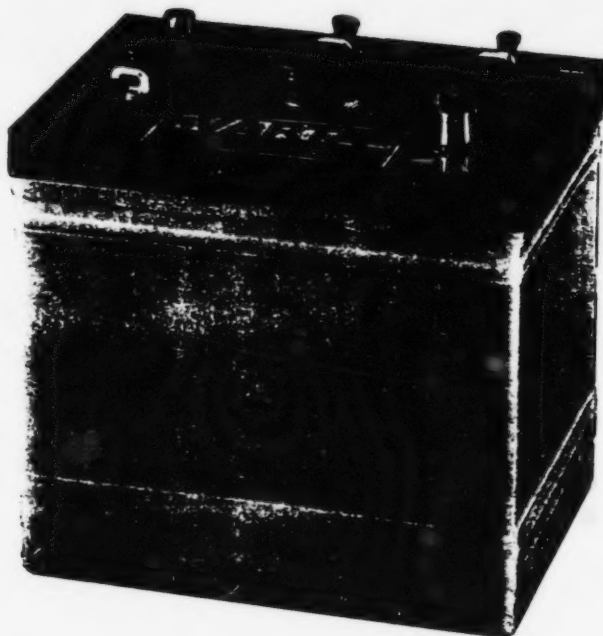
Higher capacity
and longer life
than any other battery
of equivalent type.

Description

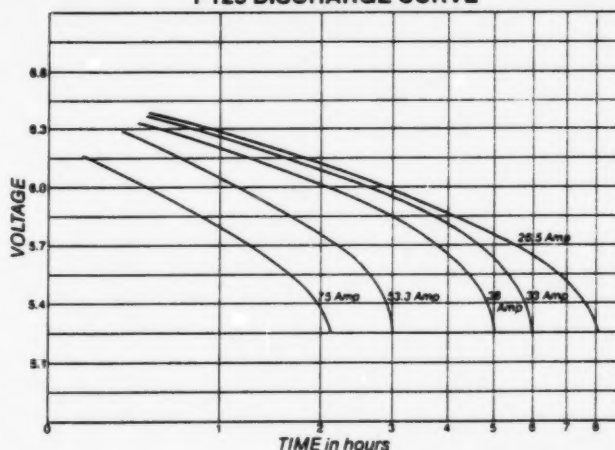
The Varta P-125 battery has been engineered from extensive experience in North American and European conditions. It combines the very best in proven modern battery technology and is manufactured in an Industrial Battery plant to Industrial Battery Standards.

The carefully selected and service tested grid alloy and the deep cycling, high density active material formulation, are identical to those used in our Industrial Traction Batteries. The positive active surface area per cell of the P-125 is more than double the surface of a five plate traction cell with a rating of 85 ampere hours per positive plate. This results in lower voltage drop and therefore better acceleration.

High performance, low resistance industrial battery separators, with bonded fiberglass mat give improved battery voltages at high rate discharge with excellent active material retention on the positive plates resulting in extended battery life. The 3 cell polypropylene monobloc container readily dissipates heat, and provides internal space for extra acid, and therefore runs cooler on charge and discharge than an equivalent five plate Traction Battery. This container provides a weight savings of about 300 lbs. over a conventional five plate traction battery package. The cycle life of the Varta P-125 is a minimum of 300 cycles and in many cases exceeds 600 cycles. This translates into a calendar life of 12 months and usually exceeds 24 months.



P125 DISCHARGE CURVE



DIMENSIONS

LENGTH		WIDTH		HEIGHT*		WEIGHT	
inch	mm.	inch	mm.	inch	mm.	lbs.	kg.
10 $\frac{1}{4}$	260	7 $\frac{1}{8}$	180	10 $\frac{3}{8}$	264	66	29.9

*Height with automotive post. Add $\frac{1}{8}$ inch or 27 mm. for wing nut adaptor.

CAPACITY

Nominal Voltage — 6 volts

Ampere Hour Capacity at:

8 hour discharge Rate	6 hour discharge Rate	5 hour discharge Rate	3 hour discharge Rate
212	197	190	160

Because of the high density active material formulation, the battery is shipped at 90% of its rated capacity and will require 80 to 90 cycles before reaching 100% of its rated capacity.

OPERATION

The Specific Gravity (S.G.) of a fully charged Varta P-125 battery should read 1.270 to 1.285 per cell at 25°C (77°F). Never discharge the battery lower than 1.140 S.G. at 25°C. Operation below 1.140 S.G. will shorten battery life. Never leave the battery in a discharged condition.

Never permit battery temperature to exceed 52°C (125°F). If necessary cease operation and allow battery to cool.

To adequately recharge a fully discharged Varta P-125 battery in 8 hours or less, a charger with an output of 40 amps. is required. When charging more than one battery simultaneously on the same charger, the P-125 batteries should be charged in series to obtain maximum performance. Due to possible variations in internal resistance from one battery to another, parallel charging is not recommended since all batteries may not be equally charged. The batteries should be given an equalizing charge at least once per month.

The electrolyte level should be checked daily, and approved water added to each cell as required to maintain electrolyte level above the separators but not higher than the cover ring.

STORAGE

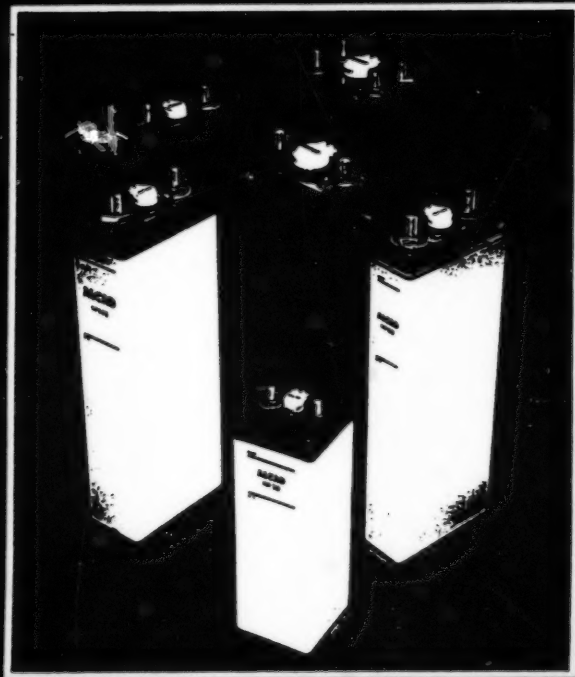
When not in use for prolonged periods, keep the fully charged battery in a cool ventilated area, and give the battery a boost charge at least once every three months.

DISTRIBUTION

The Varta P-125 battery is manufactured by the Industrial Division of Varta Batteries Ltd., 5000 François Cusson, Lachine (Montreal), Quebec, Canada. It is available from Varta agents, distributors and sales outlets worldwide, and from Barrett Battery Inc., their agents and distributors in the United States of America.

NICKEL CADMIUM BATTERIES

MP/MS SERIES FOR MEDIUM RATE DISCHARGE



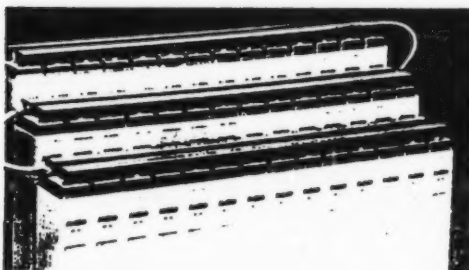
Marathon Standby Batteries

MP/MS RANGE

Marathon Versatility With an extremely wide range of nickel cadmium battery types and sizes, Marathon is able to offer the optimum package in terms of initial cost, maintenance requirements, life expectancy and, most important of all, reliability.

Benefits of Marathon Nickel Cadmium For many years, the Marathon Alcad nickel cadmium pocket plate design has been associated with long life and absolute dependability, even under extreme operating conditions.

MP and MS cells offer all the usual ALCAD advantages, including low maintenance requirements and the ability to operate efficiently at very high or very low temperatures. When the price of battery failure is too great to imagine, it pays to invest in the complete reliability of Marathon Alcad batteries.



MP Cells Polypropylene Containers

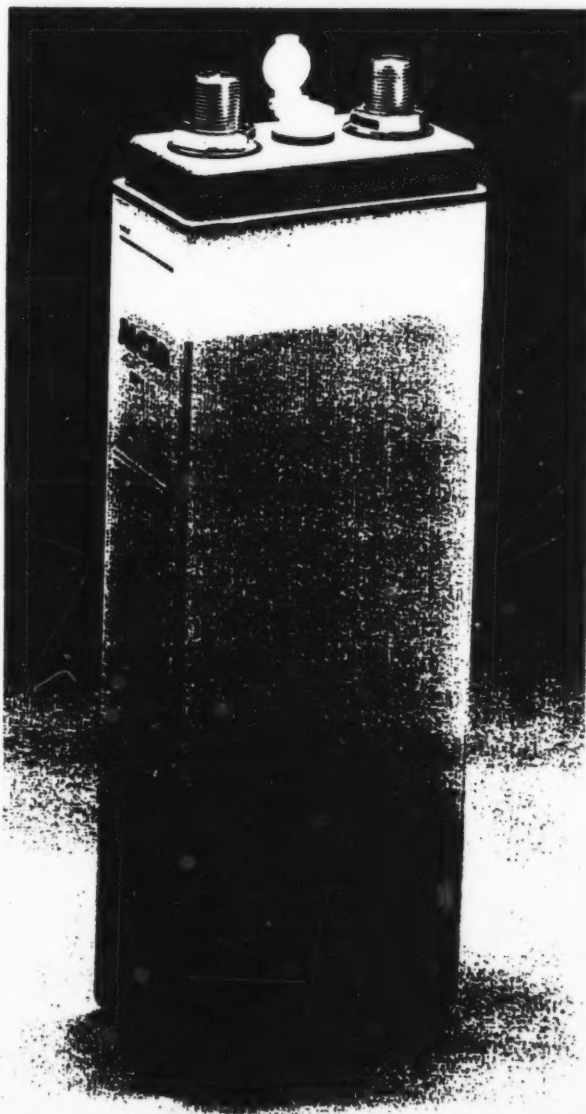
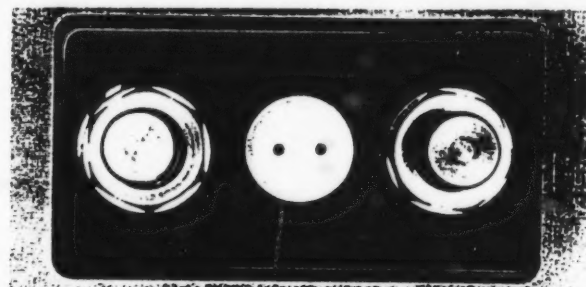
The plastic containers of Marathon Alcad MP cells are made of polypropylene, which offers excellent impact resistance combined with a high degree of translucency for easy servicing. The electrolyte reserve between maximum and minimum levels has been increased to such an extent that MP types are less costly to service than any other nickel cadmium battery.

The polypropylene lids are heat welded to the container bodies, ensuring a strong seal.

MS Cells Stainless Steel Containers

There are many applications where conditions of shock, vibration or temperature extremes require that the strongest container be used. MS cells are manufactured with rugged stainless steel containers. The cells are suspended in wooden insulating trays to provide the most durable package possible.

Medium Rate Discharge MP and MS cells are designed for medium period discharges between 30 minutes and 3 hours. As such, they offer a compromise between pure high performance and long rate discharge capacity and this makes them ideal for mixed high and low rate duty cycles such as switchgear operation and gas turbine control.



MP CELLS (plastic containers)

Cell Capacities and Dimensions



Cell Type	Capacity at 8 hr rate to 1.14 Vpc at 77°F amp hr	Volume of Electrolyte above plates cc	Weight per cell lbs	Height (H) inches	Width (W) inches	Dimensions of battery in block		
						Length (L) of block		
						1 cell inches	3 cells inches	5 cells inches
MP12	11	101	2.5	10.7	3.4	1.8	5.6	9.4
MP18	19	98	2.9	10.7	3.4	1.8	5.6	9.4
MP25	26	95	3.5	10.7	3.4	1.8	5.6	9.4
MP30	32	229	7.4	10.7	3.4	3.4	10.4	17.2
MP37	38	223	7.6	10.7	3.4	3.4	10.4	17.2
MP50	51	214	8.9	10.7	3.4	3.4	10.4	17.2
MP55	58	208	9.3	10.7	3.4	3.4	10.4	17.2
MP64	66	507	12.7	15.8	5.5	2.3	7.1	—
MP80	82	496	14.1	15.8	5.5	2.3	7.1	—
MP95	98	670	16.4	15.8	5.5	3.0	9.1	—
MP115	115	665	17.5	15.8	5.5	3.0	9.1	—
MP140	148	1184	23.9	15.8	6.5	4.1	—	—
MP160	169	1174	25.1	15.8	6.5	4.1	—	—
MP180	189	1168	26.9	15.8	6.5	4.1	—	—
MP200	210	1118	27.3	15.8	6.5	4.1	—	—
MP220	232	1413	34.4	15.8	6.5	5.1	—	—
MP240	253	1397	34.9	15.8	6.5	5.1	—	—
MP260	274	1383	36.0	15.8	6.5	5.1	—	—
MP280	295	1821	41.6	15.8	6.5	6.2	—	—
MP300	316	1715	42.3	15.8	6.5	6.2	—	—
MP320	337	1700	43.2	15.8	6.5	6.2	—	—

Height of electrolyte above plates: MP12 to MP55 - 1.6 inches
MP64 to MP320 - 3.4 inches

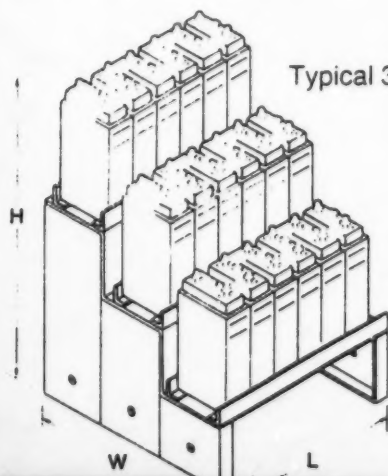
Terminals: MP12 to MP55 - 10 mm
MP64 to MP200 - 20 mm
MP220 to MP320 - 2 X 20 mm

OVERALL DIMENSIONS OF MP BATTERIES ON RACKS

Steel racks are supplied in knocked down form with insulated runners and an alkali resistant finish.

Modular construction is used with individual modules up to 60 inches long being bolted together for larger batteries.

Tiered racks and seismic racks for special installation are available.



Typical 3-step Rack

1-STEP

Cell Type	Width (inches)	Height over cells (inches)	Length (inches)		
			12V	24V	48V
MP12-25	7	17	24	48	84
MP30-55	7	17	36	72	144
MP64-80	7	22	24	48	96
MP95-115	7	22	36	72	132
MP140-200	7	22	48	84	—
MP220-260	7	22	60	108	—
MP280-320	7	22	72	144	—

2-STEP

Cell Type	Width (inches)	Height over cells (inches)	Length (inches)		
			12V	24V	48V
MP12-25	14	23	—	24	48
MP30-55	14	23	24	36	72
MP64-80	14	28	—	24	48
MP95-115	14	28	24	36	72
MP140-200	14	28	24	48	84
MP220-260	14	28	36	60	108
MP280-320	14	28	48	72	144

3-STEP

Cell Type	Width (inches)	Height over cells (inches)	Length (inches)		
			24V	48V	120V
MP12-25	21	29	—	36	60
MP30-55	21	29	—	48	120
MP64-80	21	34	—	36	84
MP95-115	21	34	—	48	96
MP140-200	21	34	36	60	144
MP220-260	21	34	36	72	168
MP280-320	21	34	48	84	204

4-STEP

Cell Type	Width (inches)	Height over cells (inches)	Length (inches)		
			24V	48V	120V
MP12-25	28	35	—	24	48
MP30-55	28	35	—	36	84
MP64-80	28	40	—	24	60
MP95-115	28	40	—	36	72
MP140-200	28	40	24	48	96
MP220-260	28	40	36	60	120
MP280-320	28	40	36	72	144

MP/MS CELLS DISCHARGE CHARACTERISTICS AT 77°F - FULLY CHARGED

Cell Type	A.H. Capacity	1 sec.	10 sec.	30 sec.	1 min.	5 min.	10 min.	30 min.	60 min.	90 min.	2 hour	3 hour	5 hour	8 hour
MP2	11	36.1	26.2	23.8	21.5	18.4	14.0	10.3	7.12	5.56	4.52	3.27	2.27	1.42
MP18	19	60.6	44.0	40.0	36.2	27.6	23.6	17.2	12.0	9.34	7.60	5.50	3.82	2.39
MP25	26	80.9	58.7	53.4	48.3	36.8	31.5	23.0	16.0	12.5	10.6	7.34	5.11	3.19
MP/S30	32	101	73.5	65.8	60.5	46.1	39.4	28.8	20.0	15.6	12.7	9.19	6.38	3.99
MP37	38	122	88.4	80.4	72.7	55.4	47.4	34.6	24.0	18.8	15.3	11.1	7.67	4.80
MP/S50	51	162	118	107	97.0	74.0	63.0	46.1	32.0	25.0	20.3	14.7	10.2	6.38
MP/S55	58	182	132	120	110	83.1	71.0	51.9	36.0	28.1	22.9	16.6	11.5	7.19
MP/S64	66	192	140	126	116	93.6	77.6	55.0	40.0	31.8	26.1	19.6	13.1	8.24
MP/S80	82	240	175	157	145	117	97.0	68.8	50.0	39.7	35.1	24.5	16.4	10.3
MP/S95	98	289	211	189	174	140	116	82.6	60.1	47.7	42.3	29.4	19.7	12.3
MP/S115	115	336	246	220	203	163	136	96.3	70.1	55.6	49.3	34.2	23.0	14.4
MP/S140	148	370	268	238	222	179	148	114	88.5	70.0	61.1	44.7	29.5	18.5
MP/S160	169	422	306	273	254	204	169	131	101	80.0	69.8	51.1	33.7	21.1
MP/S180	189	474	343	306	285	229	190	147	113	89.8	72.3	57.3	37.8	23.6
MP/S200	210	525	381	340	315	254	211	163	125	99.6	85.9	63.6	42.0	26.2
MP/S220	232	580	420	374	349	280	233	180	140	110	95.9	70.2	46.3	29.0
MP/S240	253	632	458	408	380	305	254	196	151	120	105	76.5	50.5	31.6
MP/S260	274	685	496	442	411	330	275	212	164	130	113	82.8	54.7	34.2
MP/S280	295	739	536	477	444	357	297	229	177	140	122	89.4	59.0	36.9
MP/S300	316	791	573	510	475	382	317	245	189	150	131	95.7	63.2	39.5
MP/S320	337	843	611	544	507	407	338	261	202	160	139	102	67.3	42.1
MS360	379	950	688	613	571	459	381	294	228	180	157	115	75.8	47.4
MS380	400	1102	726	646	602	484	402	310	240	190	166	121	80.0	50.0
MS420	442	1109	803	715	666	536	445	343	268	210	183	134	88.5	55.3
MS460	484	1213	879	782	729	586	487	375	290	230	200	147	96.8	60.5
MS520	548	1371	994	885	824	662	550	424	329	260	227	166	110	68.5
MS695	533	1506	1091	971	904	727	604	483	380	300	262	192	126	79.1
MS710	758	1804	1307	1165	1084	872	724	579	455	360	314	230	152	94.8
MS830	888	2106	1526	1359	1265	1017	845	676	531	420	366	268	177	111
MS950	1008	2408	1744	1553	1447	1163	966	773	607	480	419	307	202	126
MS1070	1136	2709	1963	1748	1627	1309	1087	869	683	540	471	345	228	142

Amps available to
1.14
volts per cell

Cell Type	A.H. Capacity	1 sec.	10 sec.	30 sec.	1 min.	5 min.	10 min.	30 min.	60 min.	90 min.	2 hour	3 hour	5 hour	8 hour
MS12	11	37.8	29.9	27.1	24.9	19.6	16.2	12.1	8.90	6.66	5.36	3.57	2.30	1.44
MS18	19	63.6	50.4	45.6	41.8	33.0	27.2	20.4	15.0	11.2	9.00	6.00	3.86	2.41
MS25	26	84.9	67.3	60.9	55.8	44.1	36.3	27.2	20.0	15.0	12.0	8.01	5.15	3.22
MS/S30	32	106	84.1	76.1	69.8	55.1	45.4	34.0	25.0	18.7	15.0	10.0	6.45	4.03
MP37	38	128	101	91.6	84.0	66.3	54.6	41.0	30.1	22.7	18.1	12.1	7.75	4.85
MP/S50	51	170	135	122	112	88.0	73.0	54.6	40.0	29.9	24.1	16.1	10.3	6.46
MP/S55	58	191	152	137	126	99.3	81.9	61.5	45.1	33.7	27.1	18.1	11.6	7.27
MP/S64	66	212	160	144	133	108	90.4	65.7	47.0	33.2	31.3	20.5	13.4	8.40
MP/S80	82	265	200	180	166	135	113	82.1	58.8	41.5	39.1	25.6	16.8	10.5
MP/S95	98	318	241	216	199	162	136	98.6	70.6	49.6	46.8	30.7	20.1	12.6
MP/S115	115	372	281	252	232	189	159	115	82.3	58.1	54.6	35.8	23.5	14.7
MP/S140	148	407	304	276	256	208	176	134	102	71.5	66.0	47.2	30.1	18.8
MP/S160	169	465	347	315	293	238	201	153	117	81.7	75.4	54.0	34.4	21.5
MP/S180	189	521	390	353	328	266	225	172	131	91.7	84.6	60.5	38.6	24.1
MP/S200	210	579	432	392	364	296	249	191	145	102	93.9	67.2	42.8	26.7
MP/S220	232	639	477	433	402	327	276	211	161	112	104	74.2	47.3	29.5
MP/S240	253	696	520	472	439	356	301	230	175	122	113	80.8	51.5	32.2
MP/S260	274	753	563	511	475	385	326	248	189	133	122	87.5	55.8	34.8
MP/S280	295	814	608	551	513	416	352	268	204	143	132	94.5	60.2	37.6
MP/S300	316	871	651	590	549	445	376	287	219	153	141	101	64.4	40.2
MP/S320	337	928	694	629	585	475	401	306	233	163	151	108	68.7	42.9
MS360	379	1046	781	709	659	535	452	345	262	184	169	121	77.4	48.3
MS380	400	1103	824	747	695	561	477	364	277	194	179	128	81.6	50.9
MS420	442	1220	912	827	769	624	528	402	306	214	198	142	90.3	56.4
MS460	484	1335	996	905	841	683	577	440	335	234	217	155	98.8	61.7
MS520	548	1510	1126	1023	951	772	653	498	379	265	245	175	112	69.7
MS695	633	1657	1238	1123	1044	847	716	575	438	307	283	203	129	80.6
MS710	758	1986	1484	1346	1252	1016	859	680	525	368	336	213	155	96.6
MS830	888	2319	1733	1571	1466	1186	1002	805	612	429	396	263	181	113
MS950	1008	2651	1981	1796	1670	1355	1146	920	700	490	453	324	206	129
MS1070	1136	2982	2229	2021	1879	1525	1289	1035	788	552	509	365	232	145

Amps available to
1.10
volts per cell

Volts	No. of Cells
6	5
12	9 - 10
24	18 - 20
32	25 - 27
48	36 - 37
120	92 - 95

Cell Type	A.H. Capacity	1 sec.	10 sec.	30 sec.	1 min.	5 min.	10 min.	30 min.	60 min.	90 min.	2 hour	3 hour	5 hour	8 hour
MP12	11	48.9	35.0	31.8	29.4	23.0	19.4	13.9	9.57	6.78	5.45	3.70	2.34	1.46
MP18	19	82.2	58.8	53.4	49.4	38.6	32.6	23.4	16.1	11.4	9.18	6.22	3.93	2.45
MP25	26	110	78.5	71.3	65.9	51.5	43.5	31.2	21.5	15.2	12.3	8.30	5.24	3.28
MP/S30	32	137	98.2	89.2	82.5	64.5	54.4	39.1	26.9	19.0	15.3	10.4	6.56	4.10
MP37	38	165	118	107	99.2	77.6	65.5	47.0	32.3	22.9	18.4	12.5	7.89	4.93
MP/S50	51	220	157	143	132	103	87.0	62.6	42.0	30.5	24.6	16.6	10.5	6.56
MP/S55	58	247	177	161	149	116	98.1	70.4	48.4	34.3	27.6	18.7	11.8	7.39
MP/S64	66	236	186	168	156	128	108	77.6	53.2	40.1	32.5	21.0	13.5	8.48
MP/S80	82	295	232	210	195	160	133	97.0	66.5	50.1	40.6	26.3	16.9	10.6
MP/S95	98	353	279	252	235	192	160	116	80.0	60.2	48.8	31.6	20.3	12.7
MP/S115	115	413	326	294	274	224	186	136	93.0	70.1	56.9	36.8	23.7	14.8
MP/S140	148	455	352	322	300	246	207	162	116	84.9	66.8	47.5	30.2	18.8
MP/S160	169	519	402	368	342	281	237	186	133	91.2	76.3	54.3	34.5	21.5
MP/S180	189	583	451	413	384	315	268	208	149	103	85.6	60.9	38.7	24.1
MP/S200	210	647	500	458	427	350	295	231	165	121	95.0	67.2	42.9	26.8
MP/S220	232	714	552	505	470	388	325	255	183	125	105	74.6	47.4	29.5
MP/S240	253	778	602	551	513	421	355	278	199	145	114	81.3	51.6	32.3
MP/S260	274	842	651	596	555	455	384	301	215	157	124	88.0	55.9	34.9
MP/S280	295	909	703	644	599	492	414	325	232	170	134	95.1	60.3	37.7
MP/S300	316	973	753	689	641	526	443	348	249	182	143	102	64.6	40.3
MP/S320	337	1037	807	734	683	561	473	371	265	194	152	100	62.8	43.0
MS360	379	1168	904	827	770	632	532	418	299	218	172	122	77.5	48.4
MS380	400	1232	953	873	812	667	562	440	315	230	181	129	81.8	51.1
MS420	442	1363	1055	966	899	738	621	487	349	254	200	143	90.5	56.6
MS460	484	1491	1154	1056	983	807	680	533	381	278	219	156	99.0	61.8
MS520	548	1687	1305	1195	1112	913	769	603	431	315	248	176	112	69.9
MS595	633	1852	1433	1311	1220	1002	844	697	498	364	286	204	129	80.8
MS710	758	2219	1718	1572	1463	1201	1101	835	597	436	343	244	155	96.8
MS830	888	2580	2005	1834	1707	1401	1180	974	697	509	400	285	181	113
MS950	1008	2961	2291	2097	1951	1602	1350	1114	797	582	458	326	207	129
MS1070	1136	3332	2578	2360	2196	1803	1519	1254	897	655	515	367	233	145

Amps available to

1.05
volts per cell

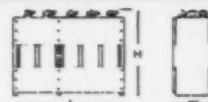
Cell Type	A.H. Capacity	1 sec.	10 sec.	30 sec.	1 min.	5 min.	10 min.	30 min.	60 min.	90 min.	2 hour	3 hour	5 hour	8 hour
MP12	11	50.1	36.6	36.3	33.8	26.3	22.7	15.8	10.2	7.02	5.68	3.74	2.37	1.48
MP18	19	81.2	58.6	57.0	58.8	44.2	38.2	26.6	12.0	11.8	9.54	6.28	3.98	2.49
MP25	26	112	88.9	81.4	75.8	58.0	51.0	35.5	23.0	15.7	12.7	8.38	5.31	3.32
MP/S30	32	141	111	102	94.9	73.8	63.8	44.4	28.7	19.7	15.9	10.5	6.65	4.16
MP37	38	166	134	123	114	88.8	76.7	53.4	34.6	23.7	19.2	12.6	8.00	5.00
MP/S50	51	225	178	163	152	118	102	71.2	46.0	31.5	25.5	16.8	10.8	6.66
MP/S55	58	253	201	184	171	133	115	80.1	51.8	35.5	28.7	18.9	12.0	7.49
MP/S64	66	261	211	192	179	146	123	89.6	57.7	41.4	33.2	21.4	13.7	8.00
MP/S80	82	326	264	240	224	183	154	112	72.1	51.8	41.5	26.8	17.1	10.8
MP/S95	98	391	318	289	269	200	185	135	86.6	62.3	49.8	32.2	20.5	12.8
MP/S115	115	456	370	336	313	257	215	157	101	72.6	58.1	37.5	23.9	14.9
MP/S140	148	502	396	368	346	285	241	179	132	91.0	69.1	48.0	30.3	18.9
MP/S160	169	574	453	421	395	325	276	204	150	104	79.0	54.9	34.7	21.6
MP/S180	189	644	508	472	443	365	309	229	167	117	88.5	61.5	39.9	24.3
MP/S200	210	715	565	524	492	404	343	254	187	129	98.4	68.3	43.1	26.9
MP/S220	232	789	622	578	543	257	379	281	207	142	109	75.3	47.6	29.7
MP/S240	253	859	678	630	592	487	413	306	225	156	118	82.1	51.9	32.4
MP/S260	274	930	734	682	640	527	447	331	244	168	126	88.9	56.2	35.1
MP/S280	295	1004	793	736	691	569	483	358	263	172	138	96.0	60.6	37.9
MP/S300	316	1075	849	788	740	609	517	383	282	194	146	103	64.9	40.5
MP/S320	337	1146	904	840	789	649	551	408	300	207	158	109	69.2	43.2
MS360	379	1291	1019	946	889	732	620	460	338	233	178	123	78.0	48.7
MS380	400	1361	1075	998	937	772	654	485	357	246	187	130	82.7	51.4
MS420	442	1506	1189	1104	1037	854	724	536	395	272	207	144	91.0	56.8
MS460	484	1648	1301	1208	1134	934	797	587	431	298	227	157	99.5	62.2
MS520	548	1864	1471	1366	1283	1056	926	664	448	327	256	178	113	70.3
MS595	633	2046	1615	1499	1408	1159	983	767	564	389	296	206	130	81.2
MS710	758	2452	1936	1797	1688	1390	1179	919	676	467	355	247	156	97.4
MS830	888	2862	2259	2098	1970	1622	1376	1073	789	545	415	288	182	113
MS950	1008	3272	2583	2398	2252	1854	1573	1226	902	623	474	329	208	130
MS1070	1136	3882	2996	2698	2535	2087	1770	1380	1015	701	534	370	234	146

Amps available to

1.00
volts per cell

MS CELLS (stainless steel containers)

Cell Capacities and Dimensions
MS cells are normally supplied in insulating wood trays.



Cell Type	Capacity at 8 hr rate to 1.14 Vpc at 77°F amp hr	Volume of Electrolyte above plates cc	Weight per cell lbs	Height (H) inches	Width (W) inches	Dimensions of battery in wood tray		
						Length (L) of tray		
						1 cell inches	3 cells inches	5 cells inches
MS30	32	210	7.4	11.4	4.4	4.6	11.7	19.2
MS50	51	195	9.5	11.4	4.4	4.6	11.7	19.2
MS55	58	190	10.1	11.4	4.4	4.6	11.7	19.2
MS64	66	422	13.9	16.7	6.3	3.6	8.4	13.1
MS80	82	410	15.4	16.7	6.3	3.6	8.4	13.1
MS95	98	435	17.3	16.7	6.3	3.8	8.7	13.7
MS115	115	520	19.1	16.7	6.3	4.1	9.8	16.0
MS140	148	640	21.6	16.7	7.4	4.1	9.8	16.0
MS160	169	725	23.7	16.7	7.4	4.4	10.7	17.6
MS180	189	825	26.4	16.7	7.4	4.8	11.8	19.4
MS200	210	910	28.7	16.7	7.4	5.1	12.7	21.0
MS220	232	995	33.9	16.7	7.4	5.5	13.8	22.7
MS240	253	1090	36.7	16.7	7.4	5.8	15.3	24.3
MS260	274	1200	38.9	16.7	7.4	6.1	16.4	-
MS280	295	1255	41.5	16.7	7.4	6.4	17.2	-
MS300	316	1365	44.2	16.7	7.4	6.8	18.3	-
MS320	337	1445	45.1	16.7	7.4	7.0	19.1	-
MS360	379	1645	51.0	16.7	7.4	7.7	21.2	-
MS380	400	1730	53.5	16.7	7.4	8.1	22.2	-
MS420	442	1900	58.1	16.7	7.4	8.7	24.1	-
MS460	484	2075	65.0	16.7	7.4	9.3	26.0	-
MS520	548	2385	76.4	16.7	7.4	10.4	30.0	-
MS595	633	2875	92.7	16.7	7.4	12.2	-	-
MS710	758	3440	107.2	16.7	7.4	14.2	-	-
MS830	888	3955	122.0	16.7	7.4	16.1	-	-
MS950	1008	4620	143.8	16.7	7.4	18.4	-	-
MS1070	1136	5220	158.8	16.7	7.4	20.5	-	-

Height of electrolyte above plates: MS30 to MS55 - 1.2 inches
MS64 to MS1070 - 2.5 inches

Terminals: MS30 to MS55 - 10 mm
MS64 to MS200 - 20 mm
MS220 to MS420 - 2 x 20 mm
MS460 to MS520 - 3 x 20 mm
MS595 to MS830 - 4 x 20 mm
MS950 to MS1070 - 6 x 20 mm

MS cells are supplied in wooden insulating trays customer specifications.

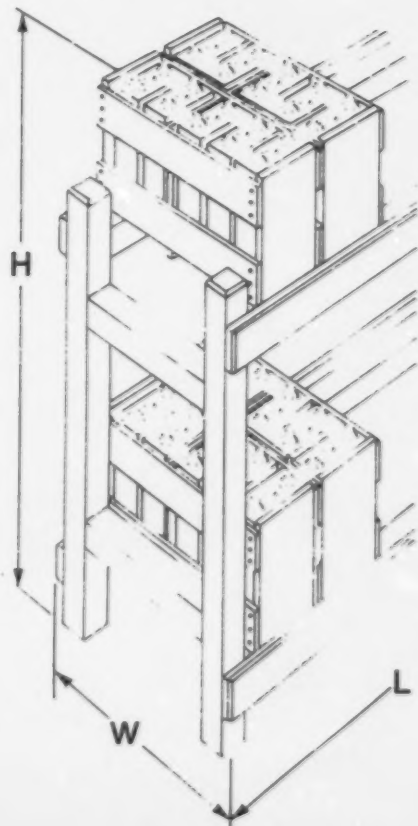
Our engineers will be happy to consult with you on the optimum tray design and arrangement for your Marathon battery.

OVERALL DIMENSIONS OF MS BATTERIES ON RACKS

Wooden racks are supplied in single or double tier versions. Typical rack dimensions are shown below.

Cell Type		Width (W) inches	SINGLE TIER			DOUBLE TIER	
			Height (H) inches	Length (L) inches		Height (H) inches	Length (L) inches
MS30-55	5 Cell Tray	21	24	22	40	51	52
MS64-80		15	29	30	56	61	75
MS95		16	29	30	56	61	75
MS115		18	29	30	56	61	75
MS140		18	29	34	65	61	86
MS160		20	29	34	65	61	86
MS180		21	29	34	65	61	86
MS200		23	29	34	65	61	86
MS220		25	29	34	65	61	86
MS240	3 Cell Tray	17	29	57	110	61	140*
MS260		18	29	57	110	61	140*
MS280		19	29	57	110	61	140*
MS300		20	29	57	110	61	140*
MS320		21	29	57	110	61	140*
MS360		23	29	57	110	61	140*
MS380		24	29	57	110	61	140*
MS420		26	29	57	110	61	140*
MS460		28	29	57	110	61	140*
MS520		32	29	57	112*	61	162*
MS595	1 Cell Tray	14	29	158*	327*	61	390*
MS710		16	29	158*	327*	61	390*
MS830		18	29	158*	327*	61	400*
MS950		20	29	158*	327*	61	400*
MS1070		23	29	158*	327*	61	425*

*Two or more racks used.



HOW TO SPECIFY

Typical specifications for Marathon medium rate MP/MS batteries are set out below.

STANDBY DUTIES

The battery shall be of the Marathon Alcad medium rate nickel cadmium pocket plate type having a nominal voltage of ... volts and consisting of ... cells type ... having an ample reserve of electrolyte to minimize maintenance. The steel cased cells shall be assembled in ... insulating trays each containing ... cells.* The battery shall be capable of delivering a current of ... amps for ... minutes to a final voltage of not less than ... volts, measured at the battery terminals at an ambient temperature of ... F. Delete if not applicable

SWITCHGEAR OPERATION

The battery shall be of the Marathon Alcad medium rate nickel cadmium pocket plate type having a nominal voltage of ... volts and consisting of ... cells type ... The plastic-cased cells shall be in individual polypropylene containers having an electrolyte reserve of not less than ... cc's to minimize maintenance. In the event of a mains failure the battery shall sustain the auxiliary load, totalling ... watts, for a period of ... hours.

At the end of this period the battery shall be capable of providing switching loads of ... amps for ... seconds to a minimum voltage of ... volts at an ambient temperature of ... F.

ABOUT MARATHON

A wholly-owned subsidiary of the Penn Central Corporation, Marathon is a manufacturing company serving worldwide energy and natural resources development, with a commitment to ALCAD nickel cadmium battery technology. At Marathon ... the technology never stops.

ENGINEERING ASSISTANCE

Marathon's staff of battery engineers are available to assist you in the selection, operation and maintenance of ALCAD nickel cadmium batteries for your particular application. A telephone call or letter is all it takes for Marathon's technology to work for you.

SERVICE- EVERYWHERE

When you install ALCAD nickel cadmium batteries with your equipment, you have the assurance that no matter where in the world that equipment will be used, a qualified battery service man is never far away. Local services are available throughout the United States and worldwide.



**Marathon
Standby
Batteries**

Marathon Standby Batteries

15 Commerce Drive
North Branford, Connecticut 06471
(203) 484-2781 Telex 956037

Represented in Canada by:
Leonard Electric (1981) Limited
1008 Rangeview Road
Mississauga, Ontario L5E 1H6 CANADA
(416) 271-2151 Telex 22 00113

Operating Instructions

For ALCAD

Pocket Plate Nickel Cadmium Alkaline Batteries

WARNING

- Limit access to only authorized personnel.
- Allow only properly trained personnel to work on a battery.
- Do not smoke, light matches or cause a spark near any storage battery.
- Remove rings and metal watchbands before working on a battery.
- Do not drop or place tools or other metal objects on a battery.
- Do not spill or splash electrolyte. Keep cells upright.
- Wear goggles or face mask when working on a battery.
- Wear additional protective equipment including apron and gloves when handling electrolyte.

CHARGING

The single, most important factor determining reliable operation and long service life is proper charging.

- Make sure the battery is given its proper initial charge at the time the battery is installed. (See the Installation Instructions on the other side of this card)
- Maintain the battery at a float voltage of 1.40 volts per cell or more.
- Higher charging voltages will recharge the battery more rapidly after it has been subjected to discharge; higher charging voltages will result in greater water consumption.
- A battery which has been subjected to a partial or complete discharge should be given a high rate charge as soon as possible so that it will be ready to perform during the next power outage.

ROUTINE MAINTENANCE

- Keep batteries clean.
- Keep intercell connectors and terminal nuts lightly coated with Komoline.
- Keep battery connections tight. Use only insulated tools when working on a battery.
- Maintain proper electrolyte levels by adding only distilled water. Never allow the electrolyte level to fall below the plate tops.

CHARGE VOLTAGE GUIDE

- 1.40-1.47 Practical float voltage range.
- 1.40-1.42 Float voltage for negligible water consumption. Should be used in conjunction with 6-monthly high rate charging for maximum capacity availability.
- 1.43-1.47 Recommended float voltage. Fully charged batteries will be maintained in a fully charged condition with low water consumption.
- 1.52-1.55 Common limiting high rate charge voltage range found in switchgear, communications, or UPS applications. This is a practical recharge voltage to be used in recharging a partially or fully discharged battery. Continuous charging at this voltage is not recommended because of high water consumption.
- 1.60-1.75 Suggested high rate charge voltage for most rapid recharge of a partially or fully discharged battery. Should be used for all installations where the connected equipment is not affected by the resultant high overall voltage or where voltage sensitive equipment can be either disconnected during recharge, or isolated by a voltage regulating device.

EMERGENCY ACTION...IN CASE OF ELECTROLYTE SPILLAGE

- Wash eyes with abundant quantities of water.
- Wash skin with abundant quantities of water.
- Remove clothing or shoes immediately if saturated or wet with electrolyte.
- Get immediate medical attention.

INSTALLATION INSTRUCTIONS

UPON RECEIPT

If the cartons or containers show signs of damage, or if there is evidence of liquid spillage, notify the carrier immediately.

The battery should be unpacked and examined for damage.

Remove all cells, hardware, connectors, tools and instruction material from the shipping containers. Check the material received against the packing list. Report shortages immediately.

Never throw away packing material until the battery is assembled and ready for operation.

Check to see that electrolyte levels are all at the 'MAX' lines. Contact the nearest ALCAD representative or the factory if there is a serious electrolyte level discrepancy.

If the battery is not to be set up for use immediately, store in cool, dry location.

SET UP:

The battery room must be adequately ventilated.

Batteries must be placed on a clean, mechanically sound supporting surface or stand, such as an ALCAD battery rack or battery console.

Place plastic container cells in position, face to face, so that electrolyte level lines can be seen. With the hardware supplied, connect the cells in series, taking care to maintain the positive-to-negative hook-up sequence throughout the battery, especially when using flexible jumpers between rows of cells on different levels.

When all intercell connectors are in place, tighten the top post nuts firmly. The proper torque value for small terminal studs (3/8" and 10mm) is approximately 120 inch pounds, and for large terminal studs (3/4" and 20mm) approximately 290 inch pounds.

The end lugs furnished with the battery should be firmly connected to the cable leads going to the external circuit. Make sure the conductors are of adequate size to limit voltage drop to the using equipment.

Before connecting the battery to the charger:

1. Check all battery connections for proper polarity and tightness.
2. Make sure the battery charger input and output are both disconnected.

Important Note: When the electrical connection between battery and the battery charger is made, connect the positive battery terminal to the positive terminal of the charger. Connect the negative battery terminal to the negative terminal of the charger.

Remove any sealing tape which may be on top of the vents.

Adjust the electrolyte level to the maximum level by adding distilled or deionized water.

INITIAL CHARGE:

It is essential that any newly installed battery be given a high rate charge, whether or not it left the factory in a charged condition.

Energize the charger. Place the charger in a high rate charge mode so that maximum current is delivered at the highest possible charge voltage setting. The charge time will depend on the current available from the charging source.

Maximum voltage available for charging	Time to charge charge current in amperes per 100 ampere hour capacity of battery:		
	5a	10a	20a
1.50 to 1.60	48 hrs	48 hrs	48 hrs
1.60 to 1.68	—	24 hrs	24 hrs
1.69 to 1.75	—	—	8 hrs

Just before termination of this commissioning charge, read and record individual cell voltages. Variation between cell voltages of 0.05 or less can be expected. With an accurate voltmeter, check the total battery voltage at the battery terminals; adjust the voltmeter reading on the charger to coincide with the battery voltage being read at the battery terminals.

Place the charger in the float charge mode, normally 1.45 volts per cell. As the decay of the high rate charge voltage may take some time and may affect the accuracy of the float voltage setting, check and re-adjust the float voltage 24 hours after the initial adjustment.

SPECIFIC GRAVITY OF ELECTROLYTE

The specific gravity of the electrolyte in ALCAD cells does not change with the state of charge.

Batteries are shipped from the factory with an electrolyte gravity of 1.190 to 1.200 at 77°F (25°C).

There is generally no need to check specific gravities on a routine basis. If the battery is subject to severe cycle service, or is being charged at excessive rates which result in the need for frequent water additions, it is suggested gravity readings be taken. Batteries should not be operated with a specific gravity below 1.145 when sampled from cells with electrolyte at the recommended maximum level, and at 77°F (25°C).

ADDITIONAL INFORMATION

Should you require further information regarding the installation, operation, or maintenance of this battery, please contact your local ALCAD representative or the factory.

Type of Cell	Nominal Capacity at 25°C/77°F	Level of electrolyte above tops of plates		Quantity of liquid electrolyte per cell	
MP	Ampere hours	mm	inches	liters	quarts
MP12	11	30	1.2	0.53	0.56
MP18	19	30	1.2	0.46	0.49
MP25	26	30	1.2	0.40	0.42
MP30	32	30	1.2	1.00	1.06
MP37	38	30	1.2	0.93	1.00
MP50	51	30	1.2	0.80	0.85
MP55	58	30	1.2	0.73	0.77
MP64	66	62	2.4	1.45	1.53
MP80	82	62	2.4	1.29	1.36
MP95	98	62	2.4	1.83	1.93
MP115	115	62	2.4	1.67	1.77
MP140	148	62	2.4	3.46	3.66
MP160	169	62	2.4	3.27	3.46
MP180	189	62	2.4	3.05	3.22
MP200	210	62	2.4	2.85	3.01
MP220	232	62	2.4	3.91	4.13
MP240	253	62	2.4	3.71	3.92
MP260	274	62	2.4	3.52	3.72
MP280	295	62	2.4	4.72	4.99
MP300	316	62	2.4	4.52	4.78
MP320	337	62	2.4	4.32	4.57

VB	Ampere hours	mm	inches	liters	quarts
VB1	14	56	2.2	0.97	1.03
VB1.5	16	56	2.2	0.90	0.95
VB2	18	56	2.2	0.88	0.93
VB3	25	56	2.2	0.83	0.88
VB4	32	56	2.2	0.77	0.81
VB5	41	56	2.2	0.69	0.73
VB6	54	56	2.2	0.57	0.60

Type of Cell	Nominal Capacity at 25°C/77°F	Level of electrolyte above tops of plates		Quantity of liquid electrolyte per cell	
UHP	Ampere hours	mm	inches	liters	quarts
UHP10	11	30	1.2	0.37	0.39
UHP14	15	30	1.2	0.44	0.47
UHP20	21	30	1.2	0.33	0.35
UHP30	32	30	1.2	0.84	0.89
UHP40	43	30	1.2	0.67	0.71
UHP50	48	30	1.2	0.61	0.64
UHP65	65	45	1.8	0.93	0.98
UHP80	88	45	1.8	1.20	1.27
UHP100	106	45	1.8	2.09	2.21
UHP125	130	45	1.8	1.73	1.83
UHP150	159	45	1.8	3.11	3.29
UHP185	200	45	1.8	2.54	2.68
UHP215	230	45	1.8	3.36	3.55
UHP235	250	45	1.8	3.07	3.24

VP	Ampere hours	mm	inches	liters	quarts
VP60	62	87	3.4	1.65	1.74
VP80	83	87	3.4	2.24	2.34
VP100	104	87	3.4	2.03	2.14
VP125	128	87	3.4	4.04	4.27
VP150	153	87	3.4	3.80	4.02
VP175	179	87	3.4	3.55	3.75
VP200	204	87	3.4	3.29	3.48
VP230	230	87	3.4	3.05	3.22
VP255	256	87	3.4	2.80	2.96
VP280	281	87	3.4	3.91	4.13
VP305	307	87	3.4	3.66	3.87
VP330	333	87	3.4	4.99	5.27
VP355	358	87	3.4	4.73	5.00
VP380	384	87	3.4	4.48	4.74

Type of Cell	Nominal Capacity at 25°C/77°F	Level of electrolyte above tops of plates		Quantity of liquid electrolyte per cell	
EP	Ampere hours	mm	inches	liters	quarts
EP0.5	54	43	1.7	0.41	0.43
EP1	10.8	43	1.7	0.37	0.39
EP2	16	25	1.0	0.33	0.35
EP2.5	24	25	1.0	0.42	0.44
EP3	32	43	1.7	0.68	0.72
EP4	43	43	1.7	0.76	0.80
EP5	54	43	1.7	0.88	0.93
EP6	64	43	1.7	0.80	0.85

LP	Ampere hours	mm	inches	liters	quarts
LP80	85	72	2.8	1.42	1.50
LP95	102	72	2.8	1.30	1.37
LP105	112	72	2.8	1.20	1.27
LP135	144	72	2.8	1.71	1.81
LP165	176	72	2.8	3.53	3.73
LP200	212	72	2.8	3.27	3.46
LP230	245	72	2.8	3.02	3.19
LP265	283	72	2.8	2.78	2.92
LP300	317	72	2.8	3.76	3.97
LP330	348	72	2.8	3.50	3.70
LP365	385	72	2.8	4.77	5.04
LP400	422	72	2.8	4.51	4.77
LP430	453	72	2.8	4.28	4.52

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